AD-A066 098 PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESE--ETC F/G 17/1
SENSITIVITY ANALYSIS IN LARGE SCALE MULTI-OBJECTIVE SYSTEMS.(U)
SEP 78 J H PERLIS N00017-73-C-1418
UNCLASSIFIED ARL/PSU/TM-78-302 NL

1 OF 2
AD
A0[illegible]809

12
NW

(6) SENSITIVITY ANALYSIS IN LARGE SCALE
MULTI-OBJECTIVE SYSTEMS.

(10) John H. Perlis

(9) Master's thesis,

(11) 27 Sep 78

(12) 169p.

Technical Memorandum
File No. TM 78-302
September 17, 1978
Contract No. N00017-73-C-1418
(15)

Copy No. 16

(14) ARL/PSU/TM-78-302

The Pennsylvania State University
Institute for Science and Engineering
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16801

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND 391 007

79 03 19 107 LB

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER TM 78-302	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SENSITIVITY ANALYSIS IN LARGE SCALE MULTI-OBJECTIVE SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED MS Thesis, November 1978
		6. PERFORMING ORG. REPORT NUMBER TM 78-302
7. AUTHOR(s) John H. Perlis		8. CONTRACT OR GRANT NUMBER(s) N00017-73-C-1418
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Pennsylvania State University Applied Research Laboratory P. O. Box 30, State College, PA 16801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Department of the Navy Washington, DC 20362		12. REPORT DATE September 17, 1978
		13. NUMBER OF PAGES 166 pages & figures
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified, Unlimited
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited,
per NSSC (Naval Sea Systems Command), 12/12/78

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

transducer
array
goal programming

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

No matter what method is employed in the programming of a transducer array, in practice the performance predicted by the model will not be achieved due to error in construction and operation of the array. Furthermore, the degree to which a given amount of error degrades an array design (i.e., design sensitivity) will differ greatly from one design to the next. A measure of sensitivity is proposed, based on the maximum impact which a given amount of error can produce on a particular design. The adoption of this measure

→ over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

20. ABSTRACT (Continued)

allows the sensitivity problem to be solved through the use of mathematical programming techniques. The best of these techniques for the general array design case is shown to be Nonlinear Goal Programming. The sensitivity values for five planar symmetric array designs are determined and compared.

The results of this comparison indicate the potential of the proposed measure and solution technique for the development of a fast and inexpensive method for array design sensitivity analysis. Particularly, the resulting sensitivity values are free from the a priori assumptions and high costs inherent in simulation. Furthermore, the method is based on a general framework which is applicable to the analysis of several array design factors inclusing size, geometry, pattern, and component reliability. The method may also be extended to multi-objective design problems outside the area of array design.

ACKNOWLEDGMENTS

The author would like to express his gratitude to Professors Benjamin Niebel, Matthew Rosenshine, and Richard Zindler, committee members, for their time and suggestions. Special gratitude is extended to Professor James Ignizio, thesis advisor, for guidance throughout the course of the study.

This research was supported by the Applied Research Laboratory under contract to the Naval Sea Systems Command.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

Figure Page

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

ABSTRACT

No matter what method is employed in the programming of a transducer array, in practice, the performance predicted by the model will not be achieved due to error in construction and operation of the array. Furthermore, the degree to which a given amount of error degrades an array design (i.e., design sensitivity) will differ greatly from one design to the next. A measure of sensitivity is proposed, based on the maximum impact which a given amount of error can produce on a particular design. The adoption of this measure allows the sensitivity problem to be solved through the use of mathematical programming techniques. The best of these techniques for the general array design case is shown to be Non-linear Goal Programming. The sensitivity values for five planar symmetric array designs are determined and compared.

The results of this comparison indicate the potential of the proposed measure and solution technique for the development of a fast and inexpensive method for array design sensitivity analysis. Particularly, the resulting sensitivity values are free from the a priori assumptions and high costs inherent in simulation. Furthermore, the method is based on a general framework which is applicable to the analysis of several array design factors including size, geometry, pattern, and component reliability. The method may also be extended to multiobjective design problems outside the area of array design.

CHAPTER I

INTRODUCTION

1.1 Purpose of the Study

Mathematical programming techniques appearing during the past 10 years have provided a means for designing complex array patterns. From 1946 until the advent of these techniques, arrays were almost universally programmed using the Dolph Tschebbyscheff method, which involved setting the directional response function equal to a Tschebbyscheff polynomial of like degree.[1,9] This method applied only to linear arrays in the exact sense. However, by the use of the product theorem, patterns produced by planar arrays could be approximated. The Dolph-Tschebbyscheff method allowed main beam width and side lobe height to be specified. In contrast, it is now possible to achieve main beam shape and place nulls, as well as achieve other objectives. A concomitant to the increased demands on array performance is a decreased tolerance of the array pattern to small deviations in the values of certain key parameters. Thus, the potential impact of error has become of increased concern to the designer. This concern provides the motivation for the present study, the purpose of which is to find a practical means of assessing array pattern sensitivity.

This process entails the choice of some measure of the impact of

error on an array pattern to serve as an indicator of sensitivity, and concurrently, the development of a method by which this measure can be evaluated. The choice reflects a compromise between attaining as much information regarding sensitivity as possible, and keeping the time and expense involved in its acquisition within reasonable limits.

The design of this study encompasses five main objectives. These are:

1. To define a consistent measure of array pattern sensitivity, which may be applied to all classes of array, and to any type of array design.
2. To develop or, more correctly, to adapt an efficient method to determine array pattern sensitivity, based on the above measure.
3. To discuss and compare alternate means for measuring and determining sensitivity.
4. To apply the chosen method to a representative problem. Specifically, on an array of given size and geometry, the sensitivities of five different array patterns, displaying a wide range of possible design features, will be determined and compared.
5. To discuss the extension of the method to the general array design sensitivity analysis problem.

1.2 Organization of the Paper

The paper is organized as follows. Chapter Two includes an introduction to transducer arrays and array patterns, pertinent terminology, coordinate systems, and conventional representations.

Methods of array pattern design using mathematical programming techniques are summarized, and error sources are discussed, as well as their resolution into variables of the directivity function.

In Chapter Three, alternate methods of measuring sensitivity are discussed. These are the expected value and the maximum value of change in the array pattern. Then, methods of finding these values are compared, including simulation and a set of mathematical optimization techniques.

MAXIM, a program which measures the maximum impact of error on an array pattern is presented, and the use of MAXIM to develop an index of sensitivity is discussed.

Chapter Four is a description of an experimental application of MAXIM. Sensitivity values are generated for five directivity patterns. The results are presented in graphic and tabular form.

These results are discussed in Chapter Five, and extensions and alternate applications of the method are suggested.

CHAPTER II

ARRAY DESIGN AND ERROR

2.1 Transducer Arrays

A transducer is any device which converts a signal from one transmission medium into a signal in another. When operating as a reciever the transducer converts a signal incident to its surface into an electric signal, and converts an electric signal into a radiated signal when operating as a transmitter.

A transducer array consists of a set of transducers, termed elements, which are placed according to some fixed geometrical arrangement, and are electrically interconnected. Arrays fall into three categories, depending on the number of physical dimensions necessary to acomodate the element positions. These are: linear, planar, and conformal, corresponding to one, two, and three dimensions, respectively.

2.2 Array Patterns

One of the major objectives involved in acoustic array design is the achievement of a desired array pattern, or equivalently, directivity pattern. If the operating array is viewed from an aspect angle, expressed as a solid angle, θ,ϕ, where the θ component is measured from the positive Z axis, and the ϕ component from the positive X axis (see

fig.2.1), the power radiated along that angle (or the sensitivity of the array to a signal incident to it from that angle) is called the directional response of the array in the θ,ϕ direction. The directional response is measured in dB. Letting θ and ϕ vary to define some region in space (often a hemisphere), the directional response at all angles contained in that region is called an array pattern. The parameters which determine the array pattern are:

1. The number and placement of elements.
2. The wavelength at which the system operates.
3. The relative amplitude and phase shading coefficients of the excitation currents to the individual elements.

Figure 2.2 is a contour plot. It represents a typical array pattern defined on $0 < \theta < 180$ and $0 < \phi < 180$. This pattern is obtained from a 10 by 10 planar symmetric array with unshaded element amplitude and phase settings. The response of the array is given on a five-degree grid in negative decibels. Thus -0 dB represents the peak power radiated in any direction, and one half of the total gain (radiated power) of the array is in the region -3 dB or less off peak. In figure 2.2 the center of this region, called the main beam, or main lobe, is at $\theta = 90$, $\phi = 90$. In this case, the axis or boresight of the array falls along the positive Y axis. Any other lobe in the array pattern with a relatively high gain , for instance at $\theta = 60$, $\phi = 90$, is considered to be noise and is called a side lobe. Likewise, any region where the gain falls below some prespecified level, say -60 dB, is termed a null, e.g.,$\theta = 15$, $\phi = 40$. Figure 2.3 is a simulated 3^d plot of the same pattern.

An array pattern may be defined in terms of three categories of

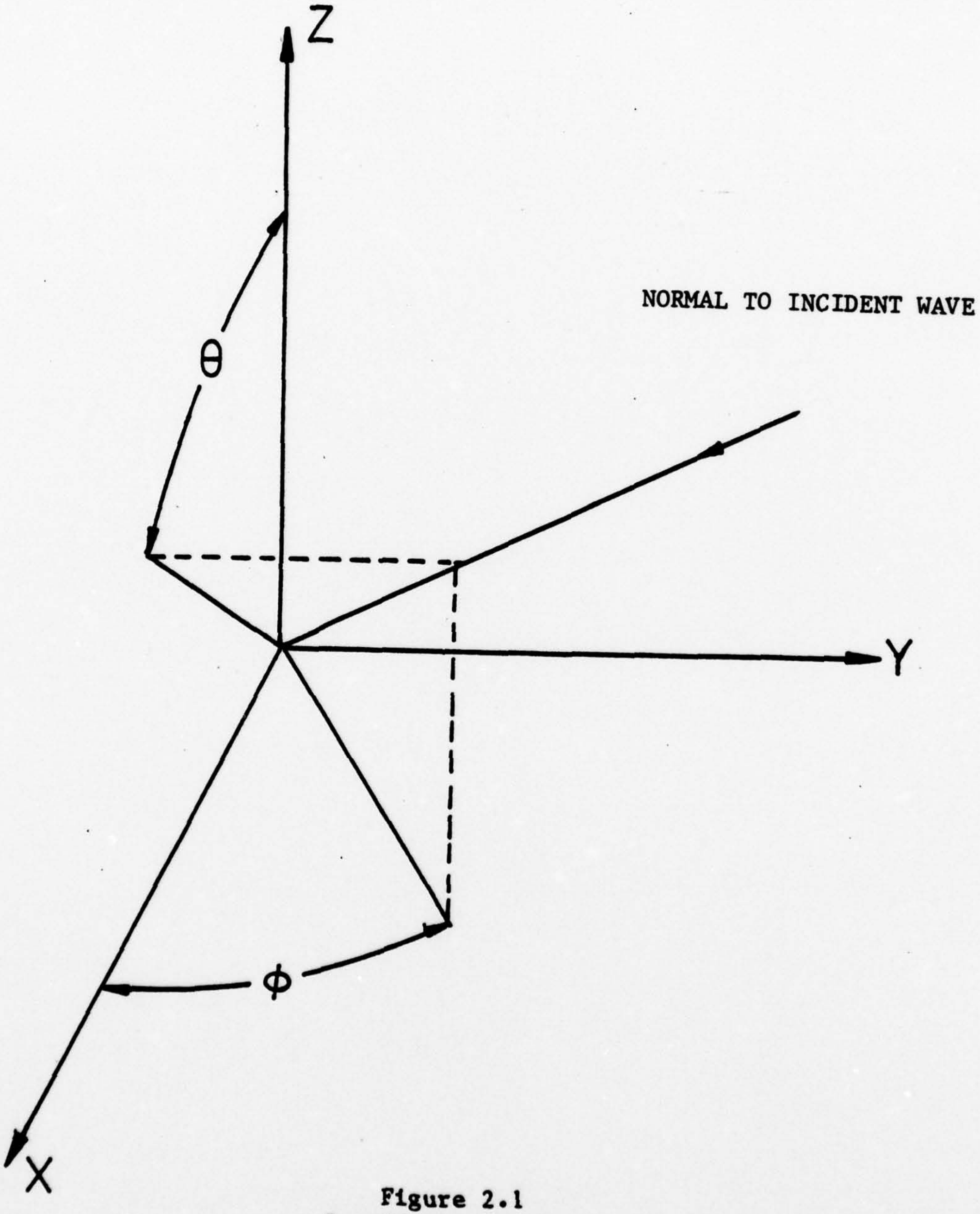


Figure 2.1
Coordinate System

```
                                BORESIGHT AT 90.90

THETA                                            PHI

        5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   5   47 47 47 46 46 46 46 46 45 45 45 45 44 44 44 44 44 44 44 44 44 44 44 44 44 45 45 45 45 46 46 46 46 46 47 47 47
  10   48 48 47 45 44 42 41 40 38 37 36 35 34 33 33 32 32 32 32 32 33 33 34 35 36 37 38 40 41 42 44 45 47 48 48
  15   39 40 40 41 42 45 50 66 46 40 35 32 30 28 27 26 26 25 26 26 27 28 30 32 35 40 46 66 50 45 42 41 40 40 39
  20   37 37 36 35 35 34 34 35 37 42 55 37 31 27 24 23 22 21 22 23 24 27 31 37 55 42 37 35 34 34 35 35 36 37 37
  25   45 47 53 62 46 40 36 34 33 33 35 45 38 29 24 21 20 19 20 21 24 29 38 45 35 33 33 34 36 40 46 62 53 47 45
  30   38 38 38 38 40 43 53 47 39 35 34 35 46 36 28 23 21 21 21 23 28 36 46 35 34 35 39 47 53 43 40 38 38 38 38
  35   55 53 51 49 47 47 47 51 66 51 45 43 45 64 40 34 31 30 31 34 40 64 45 43 45 51 66 51 47 47 47 49 51 53 55
  40   48 49 53 67 54 46 43 42 44 54 46 39 38 46 39 30 26 25 26 30 39 46 38 39 46 54 44 42 43 46 54 67 53 49 48
  45   38 38 38 39 42 51 46 38 36 37 55 37 32 34 39 25 20 19 20 25 39 34 32 37 55 37 36 38 46 51 42 39 38 38 38
  50   47 45 43 42 41 42 48 54 42 39 43 49 37 36 63 30 24 22 24 30 63 36 37 49 43 39 42 54 48 42 41 42 43 45 47
  55   57 64 62 51 47 44 45 51 53 43 43 57 42 38 50 34 27 25 27 34 50 38 42 57 43 43 53 51 45 44 47 51 62 64 57
  60   38 39 42 49 49 39 36 37 49 38 33 39 37 30 36 27 19 16 19 27 36 30 37 39 33 38 49 37 36 39 49 49 42 39 38
  65   44 44 45 47 54 57 46 43 47 54 42 43 51 38 41 36 27 24 27 36 41 38 51 43 42 54 47 43 46 57 54 47 45 44 44
  70   37 36 36 36 38 45 42 35 36 58 35 33 58 30 31 29 18 16 18 29 31 30 58 33 35 58 36 35 42 49 38 36 36 36 37
  75   38 37 35 33 34 38 50 34 33 42 35 30 47 28 28 28 16 13 16 28 28 28 47 30 35 42 33 34 50 38 34 33 35 37 38
  80   47 43 39 37 36 38 55 39 35 41 39 33 44 32 30 32 19 16 19 32 30 32 44 33 39 41 35 39 55 38 36 37 39 43 47
  85   41 33 27 24 22 24 34 27 21 25 27 19 28 18 16 19  5  2  5 19 16 18 28 19 27 25 21 27 34 24 22 24 27 33 41
  90   44 32 25 21 19 21 30 25 19 22 25 16 24 16 13 16  2  0  2 16 13 16 24 16 25 22 19 25 30 21 19 21 25 32 44
  95   41 33 27 24 22 24 34 27 21 25 27 19 28 18 16 19  5  2  5 19 16 18 28 19 27 25 21 27 34 24 22 24 27 33 41
 100   47 43 39 37 36 38 55 39 35 41 39 33 44 32 30 32 19 16 19 32 30 32 44 33 39 41 35 39 55 38 36 37 39 43 47
 105   38 37 35 33 34 38 50 34 33 42 35 30 47 28 28 28 16 13 16 28 28 28 47 30 35 42 33 34 50 38 34 33 35 37 38
 110   37 36 36 36 38 45 42 35 36 58 35 33 58 30 31 29 18 16 18 29 31 30 58 33 35 58 36 35 42 49 38 36 36 36 37
 115   44 44 45 47 54 57 46 43 47 54 42 43 51 38 41 36 27 24 27 36 41 38 51 43 42 54 47 43 46 57 54 47 45 44 44
 120   38 39 42 49 49 39 36 37 49 38 33 39 37 30 36 27 19 16 19 27 36 30 37 39 33 38 49 37 36 39 49 49 42 39 38
 125   57 64 62 51 47 44 45 51 53 43 43 57 42 38 50 34 27 25 27 34 50 38 42 57 43 43 53 51 45 44 47 51 62 64 57
 130   47 45 43 42 41 42 48 54 42 39 43 49 37 36 63 30 24 22 24 30 63 36 37 49 43 39 42 54 48 42 41 42 43 45 47
 135   38 38 38 39 42 51 46 38 36 37 55 37 32 34 39 25 20 19 20 25 39 34 32 37 55 37 36 38 46 51 42 39 38 38 38
 140   48 49 53 67 54 46 43 42 44 54 46 39 38 46 39 30 26 25 26 30 39 46 38 39 46 54 44 42 43 46 54 67 53 49 48
 145   55 53 51 49 47 47 47 51 66 51 45 43 45 64 40 34 31 30 31 34 40 64 45 43 45 51 66 51 47 47 47 49 51 53 55
 150   38 38 38 38 40 43 53 47 39 35 34 35 46 36 28 23 21 21 21 23 28 36 46 35 34 35 39 47 53 43 40 38 38 38 38
 155   45 47 53 62 46 40 36 34 33 33 35 45 38 29 24 21 20 19 20 21 24 29 38 45 35 33 33 34 36 40 46 62 53 47 45
 160   37 37 36 35 35 34 34 35 37 42 55 37 31 27 24 23 22 21 22 23 24 27 31 37 55 42 37 35 34 34 35 35 36 37 37
 165   39 40 40 41 42 45 50 66 46 40 35 32 30 28 27 26 26 25 26 26 27 28 30 32 35 40 46 66 50 45 42 41 40 40 39
 170   48 48 47 45 44 42 41 40 38 37 36 35 34 33 33 32 32 32 32 32 33 33 34 35 36 37 38 40 41 42 44 45 47 48 48
 175   47 47 47 46 46 46 46 46 45 45 45 45 44 44 44 44 44 44 44 44 44 44 44 44 44 45 45 45 45 46 46 46 46 46 47 47 47
```

Figure 2.2
Contour Plot. 10 by 10 Unshaded Array

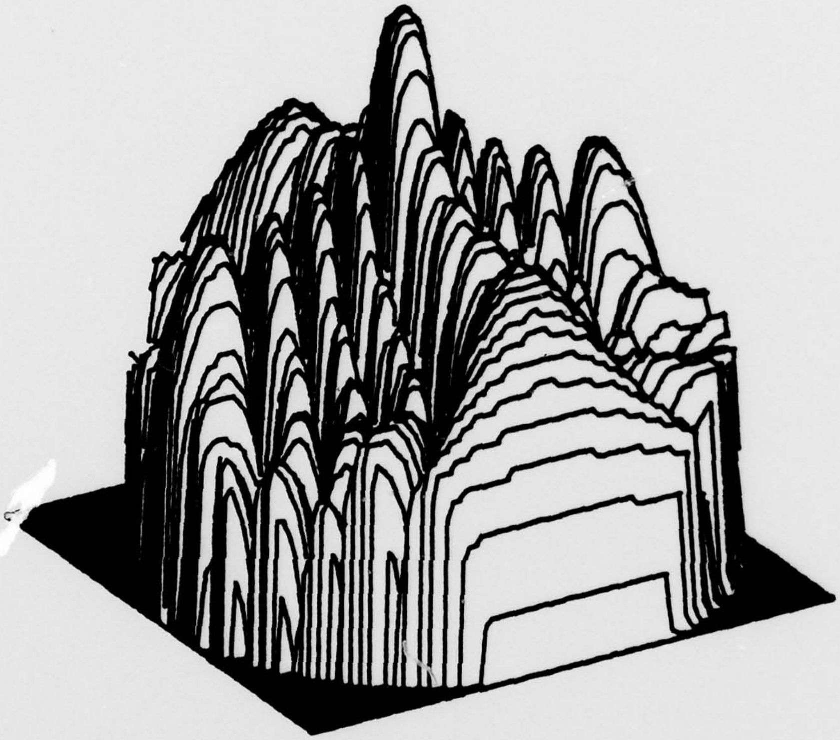


Figure 2.3
Simulated 3^d Plot. 10 by 10 Unshaded Array

design feature:

1. The size and shape of the main beam.
2. The "height" of the side lobes.
3. The placement of nulls.

2.3 Array Design Through Optimization Techniques

During the past ten years, problems in array pattern design have been successfully solved using mathematical optimization techniques. Among the methods which have been employed are Lagrangian multipliers, linear programming, method of steepest ascent, SUMT, and non-linear goal programming. Although these methods differ widely with regard to solution technique (and relative success), they usually share an underlying view of the array design problem as an optimization model in m objectives, and 2n variables. Thus an array of n independent elements, or sets of elements, is required to meet a set of specified directional responses, at m aspect angles (Θ, ϕ points), thereby defining an array pattern. In general, it is desired to maximize an objective function

$$Z(f_1(a_1,\ldots,a_{2n}),\ldots,f_m(a_1,\ldots,a_{2n}),\ f'_1,\ldots,f'_m)$$

where $f_i(a_1,\ldots,a_{2n})$ is the achieved directional response at Θ_i,ϕ_i, $a_1,\ldots a_{2n}$ are the amplitude and phase shading coefficients of the elements of the array, and f'_i is the specified response at Θ_i,ϕ_i The function Z will take on increasingly greater values as

$$f_i(a_1,\ldots,a_{2n}) \rightarrow f'_i,\quad i=1,\ldots,m$$

Due to a somewhat unfortunate overlap in terminology, the set of values which Z takes on as $a_1, \ldots, a_{2n}$ vary continuously, is called a response surface. The term "response surface" has to do with the response of the objective function and does not refer directly to the directional response of the array pattern. A response surface in 2 rather than 2n dimensions is shown in figure 2.4.The point (a'_1, a'_2) is called a global optimum. That is, there is no point (a_1, a_2) in the domain of Z such that $Z(a_1, a_2) > Z(a'_1, a'_2)$. The point (a''_1, a''_2) is a local optimum, since, although the conditions for global optimality do not hold, there exists a region given by:

$$|a_i - a''_i| < d_i, \ i=1,2, \ d_i > 0$$

such that $Z(a_1, a_2) \leq Z(a''_1, a''_2)$ holds for all a_1, a_2 within the region.

Of the optimization methods listed above, Lagrangian multipliers and linear programming are called indirect methods, since their solution techniques involve the simultaneous solution of a set of equations. The method of steepest ascent, the sequential unconstrained minimization technique, and non-linear goal programming, are direct search techniques relying on evaluation of response surface elevation, and some search movement logic to find an optimum.

Recently [10,15], Non-linear Goal Programming (NLGP), which is based on the modified Hooke and Jeeves pattern search discussed in appendix B, has been shown to provide good, robust solutions to the array design problem. The success of NLGP is due in part to the simplicity and directness of its search technique. All necessary information for search movement decisions is available directly from the objective function. Another factor in the success of NLGP derives from the goal programming problem formulation, which accommodates multiple

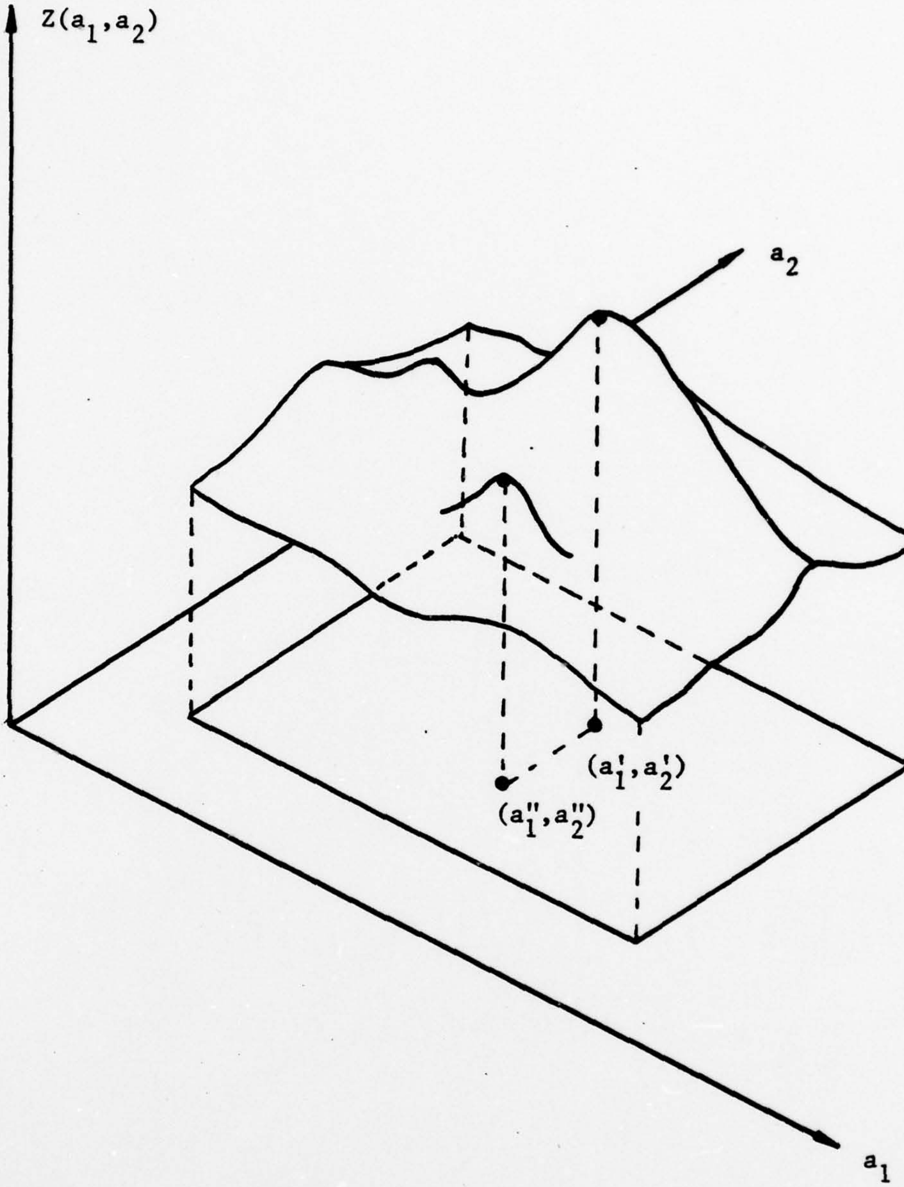


Figure 2.4
Generalized Response Surface
Showing Local and Global Optima

possibly conflicting, or even incommeasurable objectives. This particular feature of NLGP is especialy applicable to the array design problem, since the achievement of different array pattern features usually conflict. For example, it is difficult to achieve a narrow main beam, and at the same time maintain low side lobe levels.

2.4 Array Sensitivity and Error

Sensitivity analysis is the measurement of system response to deviations in the values of decision variables from those assumed in the optimal solution. The technique by which sensitivity is found is not dependent on the method originally used to obtain the solution.

If, as is often the case, the size , shape, and operating wavelength of the array have been specified in advance, the array design solution consists of a vector of element amplitude and phase shading coefficients. It happens that the values of these variables, specified in the solution are not precisely attained in practice. The reason for this may be traced to several sources of error, inherent in the construction and operation of a transducer array. The following list of error sources is not intended to be comprehensive, but to provide a representative sample.

Error sources are usually divided into two classes, depending on whether their effects on the array pattern are random or systemmatic.

The most important error source in the random category is control error in the excitation signals recieved by the individual elements. This error source is analogous to instrument drift, and will vary with time. Random construction errors in the manufacture and placement of elements, in the manufacture of phase shifters, or in the length and

fitting of feed lines will have a fixed but unpredictable effect on a given array.

Chief among the systemmatic errors is a phenomenon called mutual coupling. The signal emitted from any one element will induce a sympathetic excitation in every other element in the array. The amplitude and phase of this component of a given element's radiation depend on its position in the array, and the amplitude and phase setting of each other element. Systematic phase error may also be introduced by sensitivity of phase shifters, transmission lines, and other array components to frequency variations. Another source of phase error is the approximation inherent in discrete or digital phase shifters.

The effects of these and any other error source may be represented as a change in element amplitude and phase-shading coefficients. However, the error introduced by the mathematical model of directional response, which assumes elements with point apertures, and isotropic radiation patterns is not treated here. This error source may be resolved through refinements in the model if necessary.

CHAPTER III

THE MEASUREMENT OF SENSITIVITY

3.1 Sensitivity by Feature

In the array design problem the analyst is forced to consider the entire pattern at once, which results in a multiobjective problem formulation. This is because, as has been previously noted, the achievement of different array pattern features often conflict. While a pattern satisfying all design objectives would nominally be optimal, it probably won't be feasible. Optimality is then assigned to the "best" trade off which is both acceptable and feasible. The relative importance of different features may be reflected either in a set of weighting factors or in a preemptive priority structure. It is precisely this type of multiobjective problem which goal programming was designed to solve.

In the case where array pattern sensitivity is to be determined, however, it is more profitable to examine individual features of an array pattern separately. This is because the degradation of the different features will conflict in exactly the same manner as their achievement. By separating a pattern with, say, four important features into four different sensitivity problems, the question of deciding the relative "worst" between alternative examples of impact where different

features are affected is circumvented. With this separation, four new response surfaces may be created, each representing the achievement of one feature. Although the solution vector lies at the optimal point of the array pattern response surface, it does not follow that it lies at the optimal point of any of the individual feature response surfaces.

3.2 The Error Region and Error Surface

Consider the solution vector of an array design problem. Each component of this vector may be said to have an interval of error about it, representing the potential cumulative effects of all error sources which can be resolved into error in amplitude and phase-shading coefficients. The true value of the elements will lie somewhere along these intervals, which are expressed as plus or minus some percentage of the range over which the amplitude or phase can vary. Amplitudes are conventionally normalized to dimensionless values between 0 and 1, phase to values between 0 and 360 degrees. For an n-element array, these error intervals will form a hypercube in 2n space, with the solution vector at its center. This hypercube will be called the error region. A 2-dimensional error region is shown in figure 3.1.

If the error region is superimposed on a feature response surface, it will contain all values which that objective function which indicates the achievement of the desired feature will take on due to error. This part of the response surface will be called the error surface.

Perfect information about the sensitivity of a feature would consist of two types of data. The first of these would be a complete map of the error surface. This is equivalent to complete enumeration of the response function value over 2n continuous intervals. It is easily

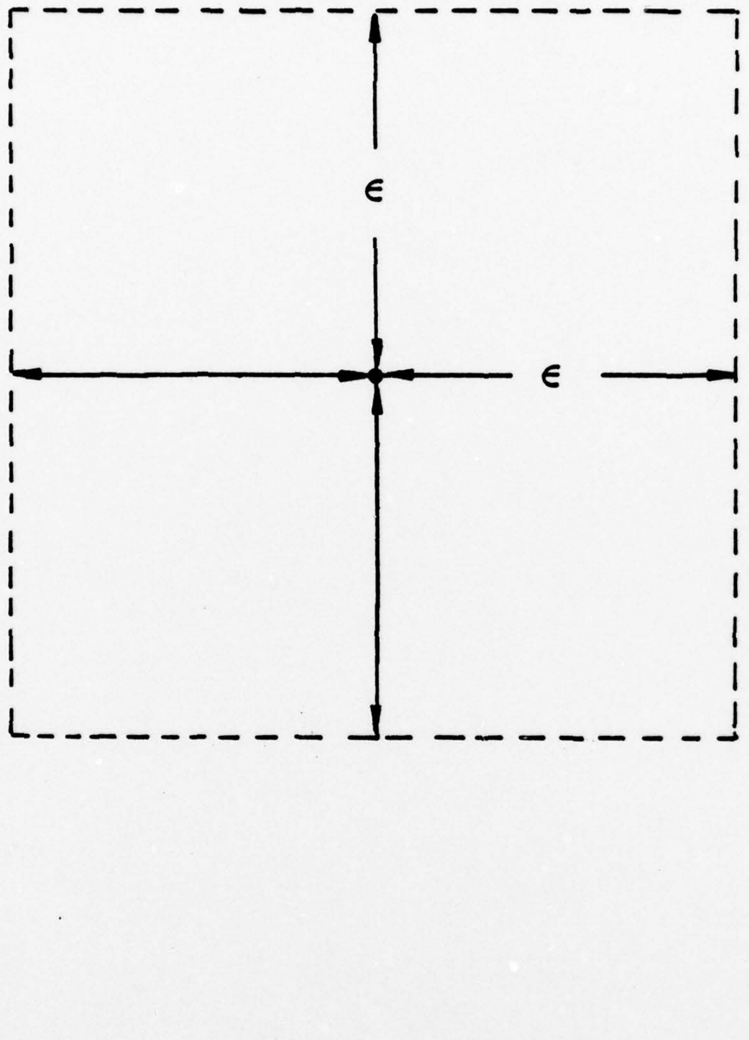


Figure 3.1
Generalized Error Region
About Design Solution Point

seen that even a low-resolution approximation would require that an astronomical number of points be evaluated as the array becomes large. For example, the array pattern of a 100 -element array depends on 200 decision variables. If the error interval of each variable is approximated by 50 equally spaced points, forming a 200 -dimensional lattice, total enumeration of the error surface response at the lattice points requires the array pattern to be evaluated 10,000 times. It should be noted as well, that as the array size increases, so does the cost of each evaluation. The second set of data would be composed of detailed knowlege of the effects of error sources. This would include such information as analysis of component interaction in various array constructions, probability distributions, the different random error types, and so forth. This kind of data is not available in practice.

Even though perfect sensitivity information is impractical or impossible to obtain, it is still desirable to find some characteristic of the error surface which will allow an assessment of sensitivity to be made. Candidates include the average elevation and the range (maximum elevation minus minimum elevation) of the error surface. The corresponding measures would be, respectively, the expected value of the feature's performance, and the worst value of the feature's performance in the error region.

3.3 Simulation

An estimate of the mean and standard deviation of the error surface elevation can be obtained by sampling points within the error region, and evaluating the objective function at these points. This amounts to a simulation of error impact. The sample will consist of a set of

points, constrained to lie within the error region, and randomly generated according to some distribution. For this purpose the distribution will usually be either normal about the solution vector, with a specified standard deviation, or uniform across the error region. Since the error sources discussed above are, in fact, partially systematic, and their random components partially fixed with regard to effect on a particular array, the assumptions inherent in these types of Monte Carlo simulations may seriously bias the analysis.

A second problem with simulation is the required sample size, and consequent expense. The number of degrees of freedom in the directivity function is twice the number of independent elements in the array. Reliable sample sizes tend to become quite large. It is noteworthy that in the 100-element case mentioned earlier (not a particularly large array), even a ten per cent sample amounts to 1000 points.

3.4 Optimization Models

Since simulation and enumeration are the only means of arriving at the expected value of array pattern feature sensitivity, and both prove to be impractical in light of present computer speeds and capacities, it remains to examine the error surface range. The maximum elevation on the error surface is assumed to be the solution vector for the array pattern. Quite a few optimization methods may be used to find the minimum elevation. These turn out to be the same techniques which have previously been brought to bear on the array design problem. It should not be surprising, considering the relationship between the two problems, that the relative success of a technique in solving one is a good predictor of performance on the other.

Representatives of three classes of optimization models will be discussed. These are:

1. Calculus-based methods.
2. Linear Programming.
3. Direct search techniques.

In order to restrict an indirect method, i.e. one based on the solution of a set of equations, to the error region, two inequality constraints must be added to the problem for each decision variable. A typical calculus-based technique for minimization subject to constraints is the use of Kuhn Tucker conditions. This method uses Lagrangian multipliers to create a set of equations which are solved simultaneously.

In the case of the general (non-symmetrical) n-element array these consist of:

1. 2n Lagrangians of the directivity function set equal to 0.
2. 4n inequality constraints.
3. 4n slack constraints, bounding the values which the multipliers may take on.

To find the minumum on a region, different combinations of the multipliers are set to 0, forcing the method to consider stationary points only along one or more boundaries of the error region. No multipliers set to 0 corresponds to the interior of the error region. This process is combinatorically explosive. At the worst case, up to 2^{4n} separate problems, each non-linear in 2n variables and 10n constraints, may have to be solved. Solving even one of these problems however, can be a somewhat monumental undertaking.

Two formulations which linearize the directivity function have been

developed. McMahon et al.[18] were the first to translate the array pattern design problem into a linear programming problem. This approach will solve for both amplitude and phase coefficients, but in order to do so, is forced to separate the real and imaginary components of the pattern. Because of this, it is impossible to reduce the problem size by taking symmetry into account.

Unlike calculus-based techniques, which are applied to the error surface, linear programming evaluates the directivity pattern. Thus a set of θ, ϕ points must be specified to define a feature which corresponds to some worst case. At each θ, ϕ point, four inequalities are generated, two each for the real and imaginary parts of the pattern. Two synthetic decision variables are developed for each element in the array, but as these are unrestricted, their number is functionally doubled. Also, for each element, four inequality constraints are added in order to define the error region.

Even before considering the number of θ, ϕ points required to define the worst case for a feature, there will be a problem in 4n variables, and 4n constraints. While this problem is orders of magnitude smaller than that generated by Kuhn Tucker conditions, its solution is still an expensive project. There will also be a certain amount of unavoidable round off error due to the subtraction and division required at each pivot.

In a later linear formulation , Wilson [20] created a linear programming problem which deals only with the real component of the pattern. Symmetry conditions may be incorporated into the directivity function in this model, and the decision variables are restricted to non-negative values. However, this drastic reduction in problem size is

accomplished at the expense of the abilty to solve for phase settings. Wilson's model assumes that all elements are excited in phase, and solves only for the amplitude coefficients. Although this technique could be easily adapted to a sensitivity analysis of the restricted (planar symmetric and unphased array) class of problem which it was intended to solve, it is not applicable to the general case.

Direct search techniques have been the most effective means of solving the general array design problem. The sequential unconstrained minimization technique, (SUMT) [11, 12], gradient search (method of steepest ascent) , and Non-linear Goal Programming [4] have all been utilized to search for an optimum directivity pattern. Summaries and comparisons of these techniques have been made by Ignizio [15] and by Draus [10]. When applied to identical pattern synthesis problems, NLGP was found to equal or exceed (sometimes markedly) the performance of the other two methods, while at the same time displaying a clear superiority in computational efficiency. These results, plus the multiobjective capacity of the goal programming formulation make NLGP the most attractive direct search technique, and by extension, the best optimization model to adapt to the general directivity pattern sensitivity problem.

3.5 MAXIM/PS

NLGP/PS is the goal programming code specifically designed for planar symmetric array pattern design. This code was written by James P. Ignizio and Susan M. Draus at the Industrial Engineering Department, and Applied Research Laboratory, The Pennsylvania State University. Its accuracy and robustness have been extensively tested.

Only minor revisions were necessary in order to adapt NLGP to search for the minimum elevation of the error surface. These changes involve parameters of the pattern search, which is described in detail in appendix B.

1. The initial step sizes were reduced to compensate for the constrained region in which the search takes place.
2. Logic was added to the evaluation of provisional base points such that any point outside the error region registers no improvement. This effectively constrains the search to the error region.
3. Changes were made in the functional relationships which define the goals, that is, the response desired at given Θ, ϕ points. In NLGP the achieved levels of response were set equal to the desired levels in the main region, and less than or equal in the side region. In the revised version, response in the main region is set less than or equal to the desired level, and in the side region, greater than or equal to the desired level.
4. The solution vector of the design problem is used as the initial base point for the pattern search.

The goal programming formulation, the directional response formulation, and the pattern search algorithm are identical in both codes. The revised version is called MAXIM/PS, as it measures the MAXimum IMpact of an error range on a feature.

Direct search techniques do not guarantee a global optimal solution on a multimodal response surface, and the Hooke and Jeeves pattern search is no exception. This is less of a problem in the array design

case, because only a satisfactory solution is required. The question of whether or not the global minumum of an error surface has been found is of greater concern , since a difference of several dB of sensitivity may be involved. In practice, however, error intervals are very small (on the order of ± 2 or 3 percent of the decision variable range), so that the chance of multimodality on any error interval, and hence on the error surface, is significantly reduced. If an extra measure of confidence is required, it is possible to make multiple search runs, commencing from different starting points.

3.6 The Index of Sensitivity

As noted previously, in the determination of pattern sensitivity important features should be considered separately. Thus, the θ, ϕ points corresponding to a high side lobe might be chosen and assigned an aspired value of -1 dB. MAXIM would then search within the error region for the point at which this side lobe was driven as high as possible. A measure on the θ, ϕ points used to define the side lobe, say the highest point or the mean height, could then be compared between the solution to the design problem and the maximum error impact solution. If the directional response at these θ, ϕ points had risen by an average of 15 dB, or if the maximum height of the feature had risen by 15 dB, the feature would be given a sensitivity value of 15 dB. The same procedure would then be repeated for all relevant features of the pattern. These would include other side lobes, nulls, and the main beam. The main beam θ, ϕ points would be given an aspired value of -60 dB to bring the response down as far as possible.

For a given error range, the result of this approach is a set of

sensitivity values associated with the important features of the array pattern. These are to be compared with minimum acceptable sensitivity values for these features. The maximum amount, in dB, by which the acceptable sensitivity value for any feature of the pattern is violated is the IOS, or index of sensitivity assigned to the pattern. Note that the IOS is specific to a given error range.

CHAPTER IV

APPLICATION: THE USE OF MAXIM TO GENERATE AN IOS

4.1 The Experiment

In order to evaluate the utility of the IOS measure of sensitivity, it was decided to test and compare a series of directivity patterns on a single array. The directivity patterns were chosen so as to reflect a broad sampling of objectives. Synthesis took place on a 10 x 10 planar symmetric array. The choice of array size and geometry was based on two considerations. The number of elements was to be large enough to produce patterns which were somewhat difficult, and hence interesting from the standpoint of sensitivity. At the same time, the number of decision variables involved was to be kept down to a reasonable level, allowing the analysis to be accomplished at a small to moderate cost in computation time.

4.2 Array Description

The 10 x 10 planar symmetric array is square and consists of 100 equally spaced elements. The elements are considered to lie in the X-Z plane, 25 elements to a quadrant, with symmetry about both the X and Z axes. The elements are placed and numbered as shown in figure 4.1. In the planar symmetric type of array, sets of four symmetrically placed

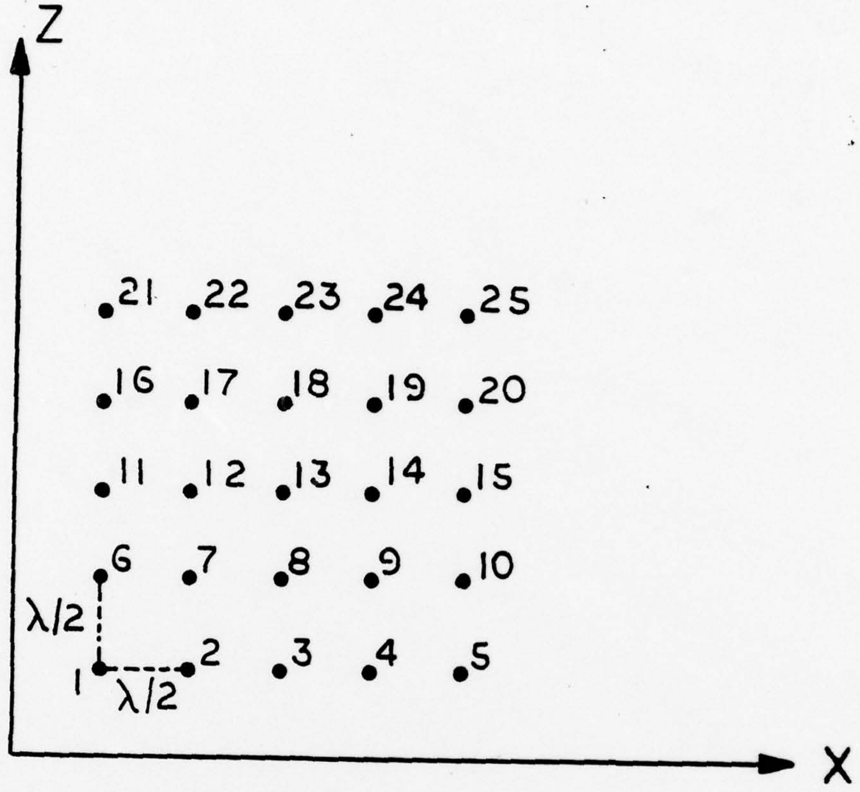


Figure 4.1
Element Positions in the First Quadrant.

elements recieve identical excitation currents. This fact decreases both the amount of hardware necessary for array construction, and the difficulty in programming the array. In the 10 x 10 case, it is necessary to consider only 25 sets of elements, a reduction from 200 to 50 decision variables.

The directivity pattern is measured over a hemisphere defined by:

$$0 \leq \theta \leq 180 \text{ and } 0 \leq \phi \leq 180$$

See figure 2.1. Thus boresight falls along the positive Y axis.

The directivity function for this array is given by:

$$G_\phi = 10 \text{ Log } [16[(\sum_{i=1}^{25} A_i \cos \alpha_i \cos b_i \cos c_i)^2 + (\sum_{i=1}^{25} A_i \sin \alpha_i \cos b_i \cos c_i)^2]]$$

where:

α_i = the phase shift associated with element i.

$b_i = 2\pi/\lambda x_i \sin\theta\cos\phi$

$c_i = 2\pi/\lambda z_i \cos\theta$

A_i = the excitation amplitude of element i.

λ = the operating wavelength of the array.

See appendix A for the derivation of this result from the general directivity function.

4.3 Experimental Patterns

Five patterns were synthesized using NLGP. This process is documented in references 10 and 15. These are:

1. 20 by 30 degree elliptical main beam with uniform response. Side lobes $\leq$ -27 dB off peak. -61 dB nulls at (20,20), (160,20), (20,160), (160,160).
2. 30 degree circular main beam with uniform response. Side lobes $\leq$ -26 dB off peak.
3. 30 degree circular main beam with uniform response. Side lobes $\leq$ -26 dB off peak. Broad nulls $\leq$ -47 dB off peak, centered about (40,35), (40,165), (140,165), (140,35), (140,165).
4. 30 degree square main beam with uniform response. Side lobes $\leq$ -28 dB off peak.
5. 30 by 70 degree rectangular main beam with uniform response. Side lobes $\leq$ -27 dB off peak.

In the discussion to follow, the experimental patterns will be referred to as patterns 1 through 5. These five patterns are illustrated by 5 degree resolution contour plots, and 2 degree resolution simulated 3^d plots in figures 4.2 to 4.11. Tables 4.12 to 4.15 show the element set amplitude and phase-shading coefficients for the five design solutions.

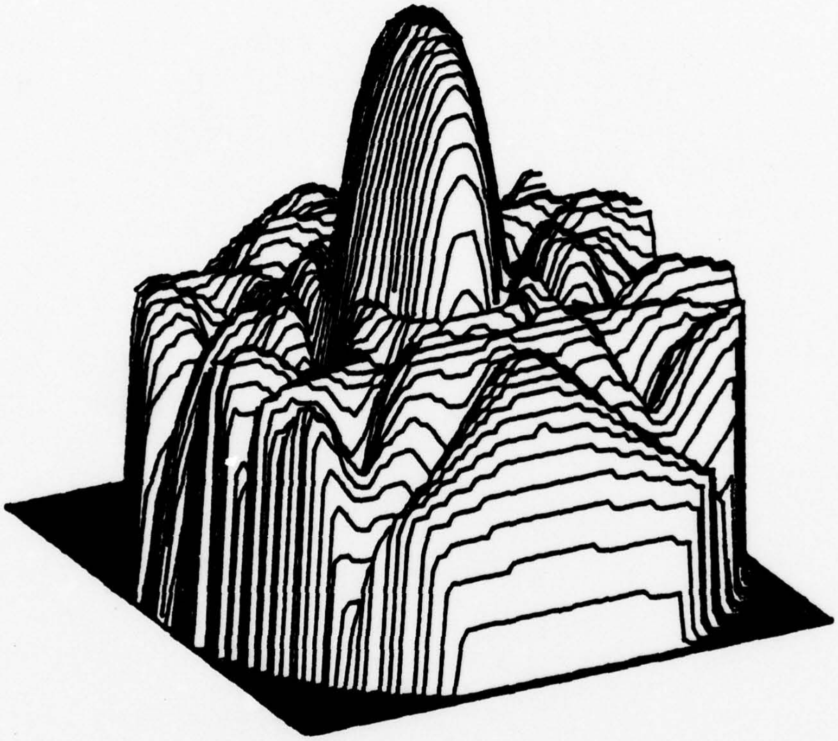


Figure 4.2
Pattern 1. Design Solution

Simulated 3^{d} Plot

```
            BORESIGHT AT 90,90
THETA                                 PHI
         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0     127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127
  5      55 55 55 55 55 55 55 55 55 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 55 55 55 55 55 55 55 55 55
 10      48 48 48 48 47 47 46 46 45 45 44 44 43 43 42 42 42 42 42 42 42 42 42 43 43 44 44 45 45 46 46 47 47 48 48 48 48
 15      50 50 50 49 48 47 46 45 44 42 41 40 39 38 37 36 35 35 35 35 35 36 37 38 39 40 41 42 44 45 46 47 48 49 50 50 50
 20      68 69 75 68 61 57 53 51 48 45 43 40 38 36 34 33 32 31 31 31 32 33 34 36 38 40 43 45 48 51 53 57 61 68 75 69 68
 25      38 38 39 40 42 45 49 52 53 53 52 49 43 38 35 32 31 30 29 30 31 32 35 38 43 49 52 53 53 52 49 45 42 40 39 38 38
 30      29 29 29 30 31 33 35 39 42 42 41 42 45 57 43 36 33 31 30 31 33 36 43 57 45 42 41 42 42 39 35 33 31 30 29 29 29
 35      27 27 27 27 27 28 30 32 35 37 36 34 33 34 35 36 35 33 32 33 35 36 35 34 33 34 36 37 35 32 30 28 27 27 27 27 27
 40      31 31 31 30 30 30 30 32 35 38 35 31 30 29 29 29 29 29 29 29 29 29 29 29 30 31 35 38 35 32 30 30 30 30 31 31 31
 45      34 34 34 33 33 32 33 35 40 49 36 31 29 28 27 27 27 28 28 28 27 27 27 28 29 31 36 49 40 35 33 32 33 33 34 34 34
 50      32 31 31 30 30 29 29 29 31 32 32 30 29 30 31 31 31 32 32 32 31 31 31 30 29 30 32 32 31 29 29 29 30 30 31 31 32
 55      53 52 49 44 39 35 33 31 30 29 28 28 31 37 35 29 28 29 29 29 28 29 35 37 31 28 28 29 30 31 33 35 39 44 49 52 53
 60      30 30 30 30 31 32 36 43 46 34 30 29 32 45 29 27 30 32 29 32 30 27 29 45 32 29 30 34 46 43 36 32 31 30 30 30 30
 65      28 28 28 27 27 27 28 29 31 35 35 31 32 31 28 36 23 16 14 16 23 36 28 31 32 31 35 35 31 29 28 27 27 27 28 28 28
 70      32 31 30 29 29 29 30 31 31 31 33 31 29 27 31 24 13  8  6  8 13 24 31 27 29 31 33 31 31 31 30 29 29 29 30 31 32
 75      39 38 36 34 33 33 37 46 35 32 33 32 28 27 33 17  8  4  3  4  8 17 33 27 28 32 33 32 35 46 37 33 33 34 36 38 39
 80      57 55 51 47 44 40 36 32 29 29 34 38 29 26 20 12  6  2  1  2  6 12 20 26 29 38 34 29 29 32 36 40 44 47 51 55 57
 85      61 55 47 42 37 35 32 30 28 28 30 36 32 24 14  8  3  1  0  1  3  8 14 24 32 36 30 28 28 30 32 35 37 42 47 55 61
 90     128 57 45 38 34 31 30 29 29 28 29 32 35 23 13  6  3  0  0  0  3  6 13 23 35 32 29 28 29 29 30 31 34 38 45 57128
 95      61 55 47 42 37 35 32 30 28 28 30 36 32 24 14  8  3  1  0  1  3  8 14 24 32 36 39 28 28 30 32 35 37 42 47 55 61
100      57 55 51 47 44 40 36 32 29 29 34 38 29 26 20 12  6  2  1  2  6 12 20 26 29 38 34 29 29 32 36 40 44 47 51 55 57
105      39 38 36 34 33 33 37 46 35 32 33 32 28 27 33 17  8  4  3  4  8 17 33 27 28 32 33 32 35 46 37 33 33 34 36 38 39
110      32 31 30 29 29 29 30 31 31 31 33 31 29 27 31 24 13  8  6  8 13 24 31 27 29 31 33 31 31 31 30 29 29 29 30 31 32
115      28 28 28 27 27 27 28 29 31 35 35 31 32 31 28 36 23 16 14 16 23 36 28 31 32 31 35 35 31 29 28 27 27 27 28 28 28
120      30 30 30 30 31 32 36 43 46 34 30 29 32 45 29 27 30 32 29 32 30 27 29 45 32 29 30 34 46 43 36 32 31 30 30 30 30
125      53 52 49 44 39 35 33 31 30 29 28 28 31 37 35 29 28 29 29 29 28 29 35 37 31 28 28 29 30 31 33 35 39 44 49 52 53
130      32 31 31 30 30 29 29 29 31 32 32 30 29 30 31 31 31 32 32 32 31 31 31 30 29 30 32 32 31 29 29 29 30 30 31 31 32
135      34 34 34 33 33 32 33 35 40 49 36 31 29 28 27 27 27 28 28 28 27 27 27 28 29 31 36 49 40 35 33 32 33 33 34 34 34
140      31 31 31 30 30 30 30 32 35 38 35 31 30 29 29 29 29 29 29 29 29 29 29 29 30 31 35 38 35 32 30 30 30 30 31 31 31
145      27 27 27 27 27 28 30 32 35 37 36 34 33 34 35 36 35 33 32 33 35 36 35 34 33 34 36 37 35 32 30 28 27 27 27 27 27
150      29 29 29 30 31 33 35 39 42 42 41 42 45 57 43 36 33 31 30 31 33 36 43 57 45 42 41 42 42 39 35 33 31 30 29 29 29
155      38 38 39 40 42 45 49 52 53 53 52 49 43 38 35 32 31 30 29 30 31 32 35 38 43 49 52 53 53 52 49 45 42 40 39 38 38
160      68 69 75 68 61 57 53 51 48 45 43 40 38 36 34 33 32 31 31 31 32 33 34 36 38 40 43 45 48 51 53 57 61 68 75 69 68
165      50 50 50 49 48 47 46 45 44 42 41 40 39 38 37 36 35 35 35 35 35 36 37 38 39 40 41 42 44 45 46 47 48 49 50 50 50
170      48 48 48 48 47 47 46 46 45 45 44 44 43 43 42 42 42 42 42 42 42 42 42 43 43 44 44 45 45 46 46 47 47 48 48 48 48
175      55 55 55 55 55 55 55 55 55 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 55 55 55 55 55 55 55 55 55
180     127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127

                 GAIN DEGRADATION IS
                   -0.237
```

Figure 4.3
Pattern 1. Design Solution
Contour Plot

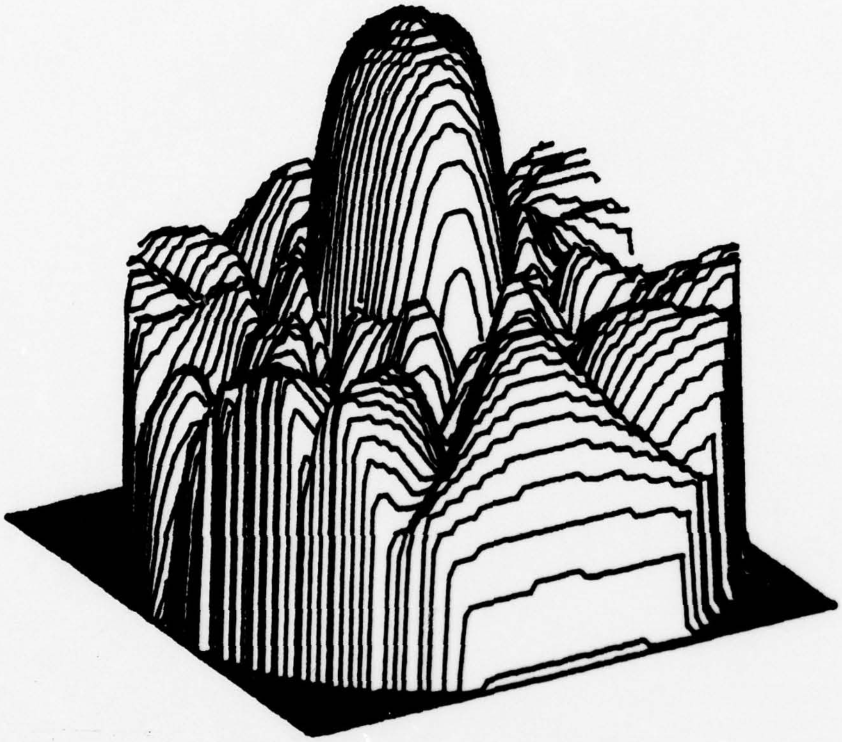


Figure 4.4
Pattern 2. Design Solution

Simulated 3^d Plot

```
            BORESIGHT AT 90,90
 THETA                                       PHI
        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0 124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124
    5  54 54 54 54 54 53 53 53 53 53 53 53 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 53 53 53 53 53 53 53 54 54 54 54 54
   10  46 46 46 46 46 45 45 44 44 43 43 42 42 41 41 41 40 40 40 40 40 41 41 41 42 42 43 43 44 44 45 45 46 46 46 46 46
   15  41 41 41 41 41 41 41 41 40 40 39 38 37 36 35 34 34 34 33 34 34 34 35 36 37 38 39 40 40 41 41 41 41 41 41 41 41
   20  34 34 34 34 35 35 35 36 36 37 37 36 35 34 33 31 30 30 29 30 30 31 33 34 35 36 37 37 36 36 35 35 35 34 34 34 34
   25  31 31 31 31 31 31 31 31 31 32 33 34 35 34 33 31 29 28 28 28 29 31 33 34 35 34 33 32 31 31 31 31 31 31 31 31 31
   30  35 35 34 33 32 30 29 29 29 29 30 31 33 35 36 34 31 29 29 29 31 34 36 35 33 31 30 29 29 29 29 30 32 33 34 35 35
   35  35 36 37 41 53 43 36 32 29 28 28 29 31 34 39 56 42 36 35 36 42 56 39 34 31 29 28 28 29 32 36 43 53 41 37 36 35
   40  27 27 28 28 29 31 36 48 37 31 29 28 30 33 35 34 33 32 32 32 33 34 35 33 30 28 29 31 37 48 36 31 29 28 28 27 27
   45  28 28 28 28 28 28 29 32 38 40 33 30 30 33 36 33 30 29 29 29 30 33 36 33 30 30 33 40 38 32 29 28 28 28 28 28 28
   50  28 28 28 28 28 29 30 32 36 42 37 32 31 33 39 55 39 35 35 35 39 55 39 33 31 32 37 42 36 32 30 29 28 28 28 28 28
   55  30 30 30 29 29 29 29 31 34 41 39 34 33 33 31 30 30 31 32 31 30 30 31 33 33 34 39 41 34 31 29 29 29 29 30 30 30
   60  35 35 35 35 35 35 34 32 32 32 34 34 34 31 28 29 37 34 29 34 37 29 28 31 34 34 34 32 32 32 34 35 35 35 35 35 35
   65  35 35 34 34 35 36 41 68 41 36 34 33 31 29 31 30 20 15 13 15 20 30 31 29 31 33 34 36 41 68 41 36 35 34 34 35 35
   70  51 50 49 47 44 41 38 36 35 36 46 36 30 32 26 16 10  7  6  7 10 16 26 32 30 36 46 36 35 36 38 41 44 47 49 50 51
   75  39 38 36 34 33 33 36 38 31 30 35 37 32 30 16  9  5  4  3  4  5  9 16 30 32 37 35 30 31 38 36 33 33 34 36 38 39
   80  42 40 37 33 31 30 33 45 31 29 43 28 26 19 10  5  3  2  2  2  3  5 10 19 26 28 43 29 31 45 33 30 31 33 37 40 42
   85  56 50 42 37 34 33 40 37 28 29 34 23 21 14  7  3  2  1  1  1  2  3  7 14 21 23 34 29 28 37 40 33 34 37 42 50 56
   90 132 58 46 40 36 37 50 33 27 29 30 21 20 13  6  3  2  1  0  1  2  3  6 13 20 21 30 29 27 33 50 37 36 40 46 58132
   95  56 50 42 37 34 33 40 37 28 29 34 23 21 14  7  3  2  1  1  1  2  3  7 14 21 23 34 29 28 37 40 33 34 37 42 50 56
  100  42 40 37 33 31 30 33 45 31 29 43 28 26 19 10  5  3  2  2  2  3  5 10 19 26 28 43 29 31 45 33 30 31 33 37 40 42
  105  39 38 36 34 33 33 36 38 31 30 35 37 32 30 16  9  5  4  3  4  5  9 16 30 32 37 35 30 31 38 36 33 33 34 36 38 39
  110  51 50 49 47 44 41 38 36 35 36 46 36 30 32 26 16 10  7  6  7 10 16 26 32 30 36 46 36 35 36 38 41 44 47 49 50 51
  115  35 35 34 34 35 36 41 68 41 36 34 33 31 29 31 30 20 15 13 15 20 30 31 29 31 33 34 36 41 68 41 36 35 34 34 35 35
  120  35 35 35 35 35 35 34 32 32 32 34 34 34 31 28 29 37 34 29 34 37 29 28 31 34 34 34 32 32 32 34 35 35 35 35 35 35
  125  30 30 30 29 29 29 29 31 34 41 39 34 33 33 31 30 30 31 32 31 30 30 31 33 33 34 39 41 34 31 29 29 29 29 30 30 30
  130  28 28 28 28 28 29 30 32 36 42 37 32 31 33 39 55 39 35 35 35 39 55 39 33 31 32 37 42 36 32 30 29 28 28 28 28 28
  135  28 28 28 28 28 28 29 32 38 40 33 30 30 33 36 33 30 29 29 29 30 33 36 33 30 30 33 40 38 32 29 28 28 28 28 28 28
  140  27 27 28 28 29 31 36 48 37 31 29 28 30 33 35 34 33 32 32 32 33 34 35 33 30 28 29 31 37 48 36 31 29 28 28 27 27
  145  35 36 37 41 53 43 36 32 29 28 28 29 31 34 39 56 42 36 35 36 42 56 39 34 31 29 28 28 29 32 36 43 53 41 37 36 35
  150  35 35 34 33 32 30 29 29 29 29 30 31 33 35 36 34 31 29 29 29 31 34 36 35 33 31 30 29 29 29 29 30 32 33 34 35 35
  155  31 31 31 31 31 31 31 31 31 32 33 34 35 34 33 31 29 28 28 28 29 31 33 34 35 34 33 32 31 31 31 31 31 31 31 31 31
  160  34 34 34 34 35 35 35 36 36 37 37 36 35 34 33 31 30 30 29 30 30 31 33 34 35 36 37 37 36 36 35 35 35 34 34 34 34
  165  41 41 41 41 41 41 41 41 40 40 39 38 37 36 35 34 34 34 33 34 34 34 35 36 37 38 39 40 40 41 41 41 41 41 41 41 41
  170  46 46 46 46 46 45 45 44 44 43 43 42 42 41 41 41 40 40 40 40 40 41 41 41 42 42 43 43 44 44 45 45 46 46 46 46 46
  175  54 54 54 54 54 53 53 53 53 53 53 53 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 53 53 53 53 53 53 53 54 54 54 54 54
  180 124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124

                 GAIN DEGRADATION IS
                   -9.215
```

Figure 4.5
Pattern 2. Design Solution
Contour Plot

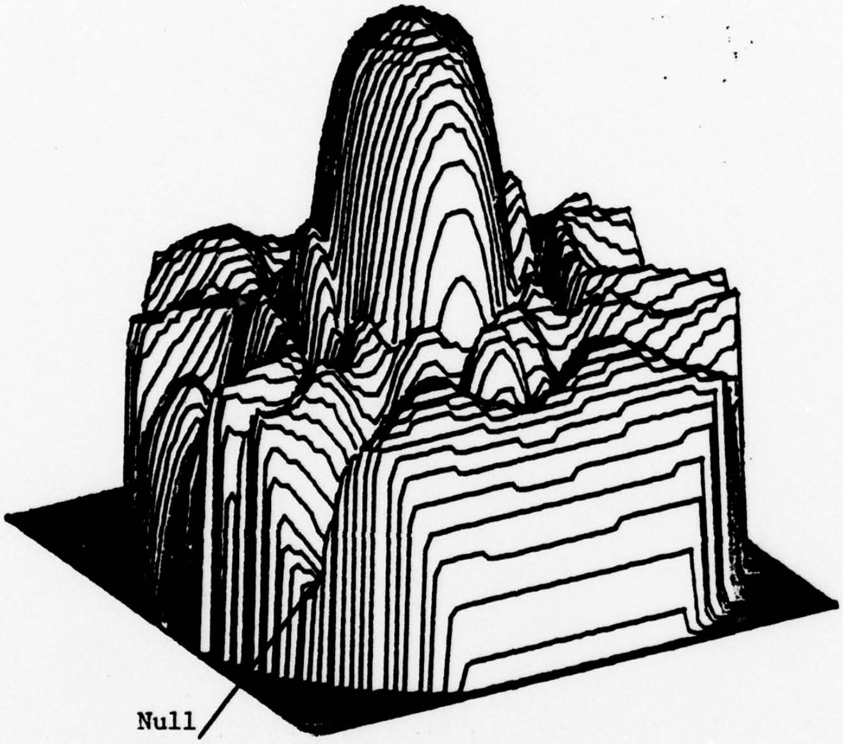


Figure 4.6
Pattern 3. Design Solution

Simulated 3^d Plot

```
        BORESIGHT AT 90,90
THETA                                          PHI

       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0  130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130
  5   57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57
 10   44 44 44 44 44 44 44 44 44 44 44 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 44 44 44 44 44 44 44 44 44 44 44
 15   38 38 38 38 38 38 37 37 37 37 37 37 38 38 38 38 39 39 39 39 39 38 38 38 38 37 37 37 37 37 37 38 38 38 38 38 38
 20   38 38 37 37 36 36 35 34 34 33 33 33 33 33 34 34 35 35 35 35 35 34 34 33 33 33 33 33 34 34 35 36 36 37 37 38 38
 25   43 43 42 41 40 38 37 35 34 32 31 31 31 31 31 32 33 34 35 34 33 32 31 31 31 31 31 32 34 35 37 38 40 41 42 43 43
 30   55 55 55 55 52 48 44 40 37 34 32 31 30 30 31 33 36 39 40 39 36 33 31 30 30 31 32 34 37 40 44 48 52 55 55 55 55
 35   47 47 48 48 49 51 54 54 47 41 36 33 31 31 32 37 47 41 38 41 47 37 32 31 31 33 36 41 47 54 54 51 49 48 48 47 47
 40   45 45 46 47 48 49 50 51 51 50 44 38 35 34 35 39 35 30 29 30 35 39 35 34 35 38 44 50 51 51 50 49 48 47 46 45 45
 45   37 37 38 39 40 42 44 46 49 49 48 44 40 37 38 40 34 30 28 30 34 40 38 37 40 44 48 49 49 46 44 42 40 39 38 37 37
 50   32 32 32 33 33 33 34 35 37 40 42 43 42 38 36 37 46 41 37 40 46 37 36 38 42 43 42 40 37 35 34 33 33 33 32 32 32
 55   36 36 36 36 35 33 32 31 31 32 35 37 37 34 31 29 29 30 31 30 29 29 31 34 37 37 35 32 31 31 32 33 35 36 36 36 36
 60   37 37 37 38 40 41 37 33 31 30 31 32 32 31 30 30 35 33 31 33 35 30 30 31 32 32 31 30 31 33 37 41 40 38 37 37 37
 65   32 32 31 31 30 30 31 32 33 33 33 31 29 29 35 28 19 15 13 15 19 28 35 29 29 31 33 33 33 32 31 30 30 31 31 32 32
 70   38 37 36 34 33 31 30 29 30 33 41 33 29 30 24 16 10  7  6  7 10 16 24 30 29 33 41 33 30 29 30 31 33 34 36 37 38
 75   44 43 41 39 37 36 34 31 29 30 38 34 32 27 15  9  6  4  3  4  6  9 15 27 32 34 38 30 29 31 34 36 37 39 41 43 44
 80   46 44 40 37 35 35 39 35 29 30 42 27 29 19 10  5  3  2  2  2  3  5 10 19 29 27 42 30 29 35 39 35 35 37 40 44 46
 85   59 53 45 40 37 38 54 33 27 29 34 23 23 15  7  3  2  2  1  2  2  3  7 15 23 23 34 29 27 33 54 38 37 40 45 53 59
 90  135 60 48 42 39 42 44 30 26 29 31 21 22 13  6  3  2  1  0  1  2  3  6 13 22 21 31 29 26 30 44 42 39 42 48 60135
 95   59 53 45 40 37 38 54 33 27 29 34 23 23 15  7  3  2  2  1  2  2  3  7 15 23 23 34 29 27 33 54 38 37 40 45 53 59
100   46 44 40 37 35 35 39 35 29 30 42 27 29 19 10  5  3  2  2  2  3  5 10 19 29 27 42 30 29 35 39 35 35 37 40 44 46
105   44 43 41 39 37 36 34 31 29 30 38 34 32 27 15  9  6  4  3  4  6  9 15 27 32 34 38 30 29 31 34 36 37 39 41 43 44
110   38 37 36 34 33 31 30 29 30 33 41 33 29 30 24 16 10  7  6  7 10 16 24 30 29 33 41 33 30 29 30 31 33 34 36 37 38
115   32 32 31 31 30 30 31 32 33 33 33 31 29 29 35 28 19 15 13 15 19 28 35 29 29 31 33 33 33 32 31 30 30 31 31 32 32
120   37 37 37 38 40 41 37 33 31 30 31 32 32 31 30 30 35 33 31 33 35 30 30 31 32 32 31 30 31 33 37 41 40 38 37 37 37
125   36 36 36 36 35 33 32 31 31 32 35 37 37 34 31 29 29 30 31 30 29 29 31 34 37 37 35 32 31 31 32 33 35 36 36 36 36
130   32 32 32 33 33 33 34 35 37 40 42 43 42 38 36 37 46 41 37 41 46 37 36 38 42 43 42 40 37 35 34 33 33 33 32 32 32
135   37 37 38 39 40 42 44 46 49 49 48 44 40 37 38 40 34 30 28 30 34 40 38 37 40 44 48 49 49 46 44 42 40 39 38 37 37
140   45 45 46 47 48 49 50 51 51 50 44 38 35 34 35 39 35 30 29 30 35 39 35 34 35 38 44 50 51 51 50 49 48 47 46 45 45
145   47 47 48 48 49 51 54 54 47 41 36 33 31 31 32 37 47 41 38 41 47 37 32 31 31 33 36 41 47 54 54 51 49 48 48 47 47
150   55 55 55 55 52 48 44 40 37 34 32 31 30 30 31 33 36 39 40 39 36 33 31 30 30 31 32 34 37 40 44 48 52 55 55 55 55
155   43 43 42 41 40 38 37 35 34 32 31 31 31 31 31 32 33 34 35 34 33 32 31 31 31 31 31 32 34 35 37 38 40 41 42 43 43
160   38 38 37 37 36 36 35 34 34 33 33 33 33 33 34 34 35 35 35 35 35 34 34 33 33 33 33 33 34 34 35 36 36 37 37 38 38
165   38 38 38 38 38 38 37 37 37 37 37 37 38 38 38 38 39 39 39 39 39 38 38 38 38 37 37 37 37 37 37 38 38 38 38 38 38
170   44 44 44 44 44 44 44 44 44 44 44 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 44 44 44 44 44 44 44 44 44 44 44
175   57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57
180  130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130

                  GAIN DEGRADATION IS
                     -9.301
```

Figure 4.7
Pattern 3. Design Solution
Contour Plot

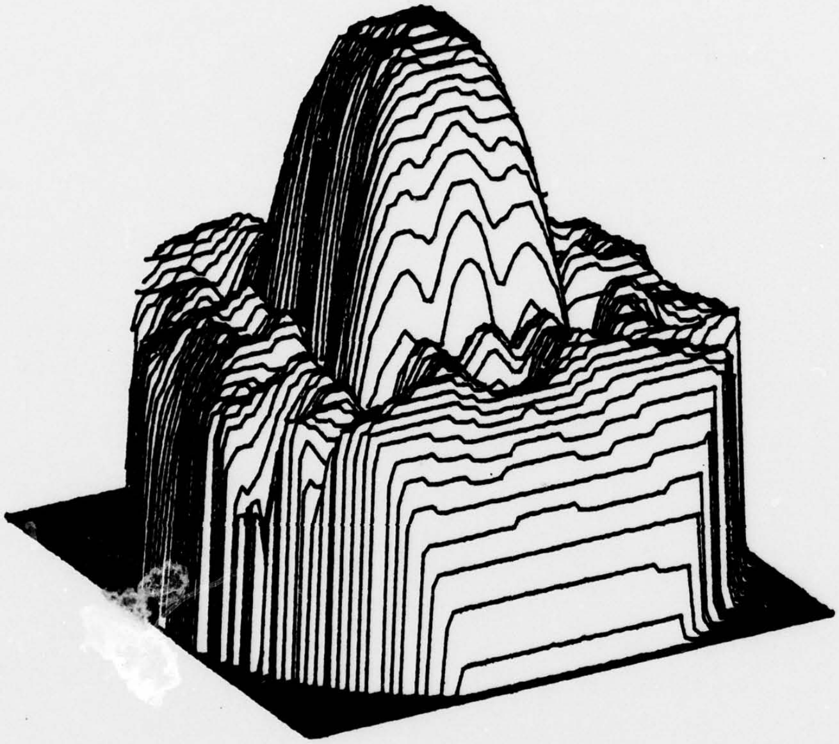


Figure 4.8
Pattern 4. Design Solution

Simulated 3^d Plot

```
          BORESIGHT AT 90,90

THETA                             PHI

        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0   126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126
  5    56 56 56 56 56 56 56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56 56 56 56 56 56 56
 10    43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 44 43 43 43 44 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43
 15    36 36 36 36 36 36 36 36 36 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 36 36 36 36 36 36 36 36 36 36
 20    32 32 32 32 32 32 32 31 31 31 31 32 32 33 33 33 33 33 32 33 33 33 33 33 32 32 31 31 31 31 32 32 32 32 32 32 32
 25    33 33 32 32 31 31 30 30 29 29 29 29 29 29 30 30 31 30 30 30 31 30 30 29 29 29 29 29 29 30 30 31 31 32 32 33 33
 30    44 44 42 39 36 34 32 30 29 29 29 28 28 28 28 29 30 31 31 31 30 29 28 28 26 28 29 29 29 30 32 34 36 39 42 44 44
 35    32 32 33 34 36 38 37 34 31 30 30 30 30 29 29 30 32 35 37 35 32 30 29 29 30 30 33 30 31 34 37 38 36 34 33 32 32
 40    32 32 32 32 32 32 33 33 32 32 32 33 33 31 30 31 35 39 37 39 35 31 30 31 33 33 32 32 32 33 33 32 32 32 32 32 32
 45    40 41 43 44 40 36 33 31 30 30 32 34 33 30 29 31 34 30 28 30 34 31 29 30 33 34 32 30 30 31 33 36 40 44 43 41 40
 50    34 34 36 39 46 46 37 33 31 31 32 34 33 30 29 30 32 30 29 30 32 30 29 30 33 34 32 31 31 33 37 46 46 39 36 34 34
 55    36 36 38 41 46 41 36 33 32 33 38 47 51 41 36 37 40 32 29 32 40 37 36 41 51 47 38 33 32 33 36 41 46 41 38 36 36
 60    34 34 34 34 33 32 31 30 31 36 52 33 26 21 20 20 21 17 15 17 21 20 20 21 26 33 52 36 31 30 31 32 33 34 34 34 34
 65    33 33 32 32 31 31 30 30 31 35 38 28 20 15 12 12 12 10  9 10 12 12 12 15 20 28 38 35 31 30 30 31 31 32 32 33 33
 70    34 34 33 32 31 31 33 36 40 39 37 29 19 12  8  6  6  5  5  5  6  6  8 12 19 29 37 39 40 36 33 31 31 32 33 34 34
 75    37 36 34 32 30 30 30 32 32 33 39 36 21 12  7  4  3  3  3  3  3  4  7 12 21 36 39 33 32 32 30 30 30 32 34 36 37
 80    42 40 37 33 30 29 29 30 29 29 36 41 23 12  6  3  2  2  2  2  2  3  6 12 23 41 36 29 29 30 29 29 30 33 37 40 42
 85    54 48 40 34 31 29 29 33 32 29 31 30 18 10  5  3  2  1  0  1  2  3  5 10 18 30 31 29 32 33 29 29 31 34 40 48 54
 90   126 54 42 35 31 29 29 34 34 29 30 26 17  9  4  3  2  1  0  1  2  3  4  9 17 28 30 29 34 34 29 29 31 35 42 54126
 95    54 48 40 34 31 29 29 33 32 29 31 30 18 10  5  3  2  1  0  1  2  3  5 10 18 30 31 29 32 33 29 29 31 34 40 48 54
100    42 40 37 33 30 29 29 30 29 29 36 41 23 12  6  3  2  2  2  2  2  3  6 12 23 41 36 29 29 30 29 29 30 33 37 40 42
105    37 36 34 32 30 30 30 32 32 33 39 36 21 12  7  4  3  3  3  3  3  4  7 12 21 36 39 33 32 32 30 30 30 32 34 36 37
110    34 34 33 32 31 31 33 36 40 39 37 29 19 12  8  6  6  5  5  5  6  6  8 12 19 29 37 39 40 36 33 31 31 32 33 34 34
115    33 33 32 32 31 31 30 30 31 35 38 28 20 15 12 12 12 10  9 10 12 12 12 15 20 28 38 35 31 30 30 31 31 32 32 33 33
120    34 34 34 34 33 32 31 30 31 36 52 33 26 21 20 20 21 17 15 17 21 20 20 21 26 33 52 36 31 30 31 32 33 34 34 34 34
125    36 36 38 41 46 41 36 33 32 33 38 47 51 41 36 37 40 32 29 32 40 37 36 41 51 47 38 33 32 33 36 41 46 41 38 36 36
130    34 34 36 39 46 46 37 33 31 31 32 34 33 30 29 30 32 30 29 30 32 30 29 30 33 34 32 31 31 33 37 46 46 39 36 34 34
135    40 41 43 44 40 36 33 31 30 30 32 34 33 30 29 31 34 30 28 30 34 31 29 30 33 34 32 30 30 31 33 36 40 44 43 41 40
140    32 32 32 32 32 32 33 33 32 32 32 33 33 31 30 31 35 39 37 39 35 31 30 31 33 33 32 32 32 33 33 32 32 32 32 32 32
145    32 32 33 34 36 37 37 34 31 30 30 30 30 29 29 30 32 35 37 35 32 30 29 29 30 30 30 30 31 34 37 37 36 34 33 32 32
150    44 44 42 39 36 34 32 30 29 29 29 28 28 28 28 29 30 31 31 31 30 29 28 28 28 28 29 29 29 30 32 34 36 39 42 44 44
155    33 33 32 32 31 31 30 30 29 29 29 29 29 29 30 30 31 30 30 30 31 30 30 29 29 29 29 29 29 30 30 31 31 32 32 33 33
160    32 32 32 32 32 32 32 31 31 31 31 32 32 33 33 33 33 33 32 33 33 33 33 33 32 32 31 31 31 31 32 32 32 32 32 32 32
165    36 36 36 36 36 36 36 36 36 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 36 36 36 36 36 36 36 36 36 36
170    43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43
175    56 56 56 56 56 56 56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56 56 56 56 56 56 56
180   126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126

             GAIN DEGRADATION IS
              -10.643
```

Figure 4.9
Pattern 4. Design Solution
Contour Plot

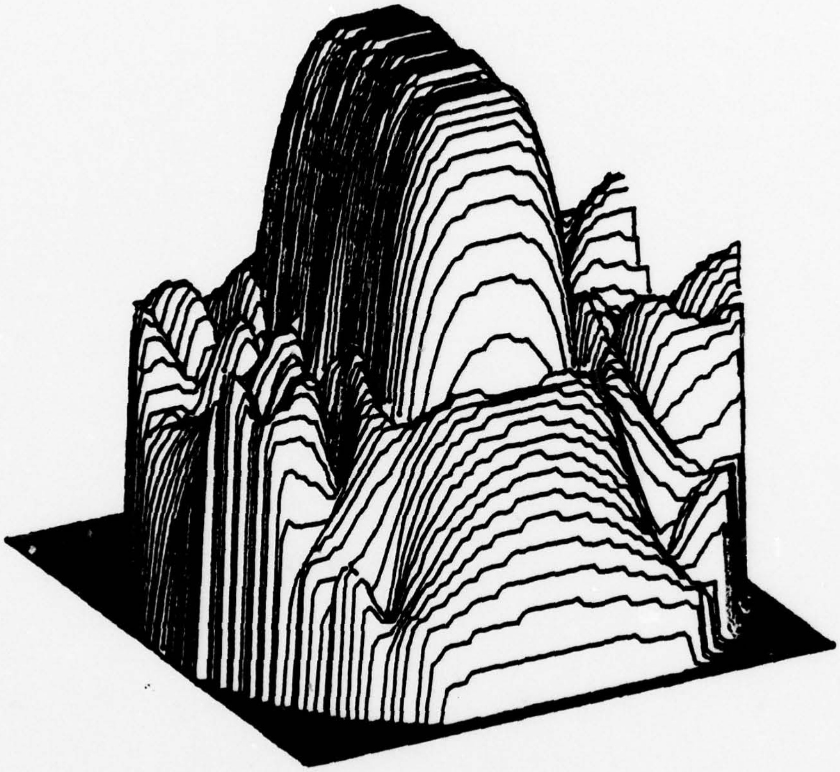
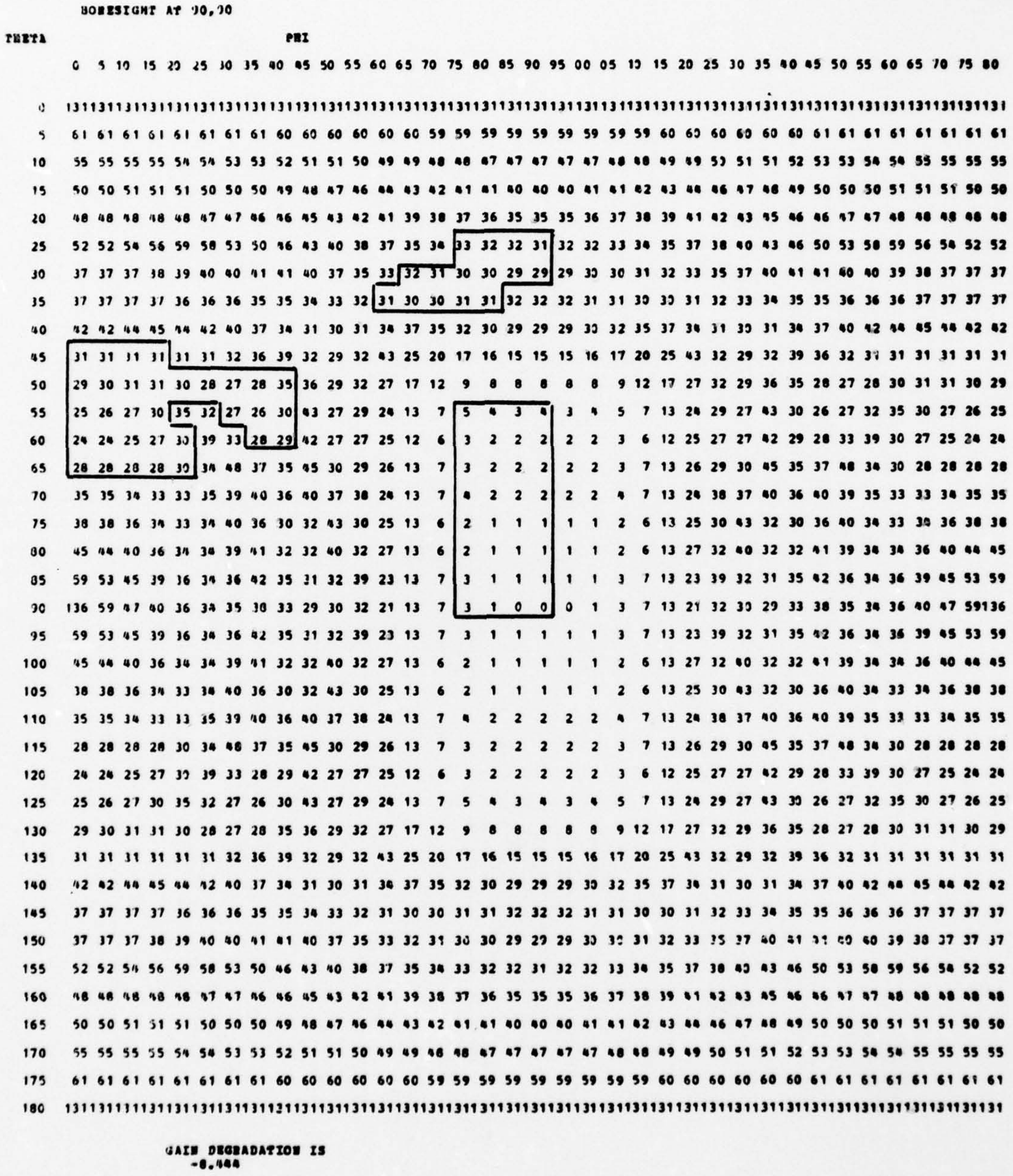


Figure 4.10
Pattern 5. Design Solution

Simulated 3^d Plot



```
          BORESIGHT AT 90,90

THETA                            PHI

       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0  131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131
   5   61 61 61 61 61 61 61 61 60 60 60 60 60 60 59 59 59 59 59 59 59 59 59 60 60 60 60 60 60 61 61 61 61 61 61 61 61
  10   55 55 55 55 54 54 53 53 52 51 51 50 49 49 48 48 47 47 47 47 47 48 48 49 49 50 51 51 52 53 53 54 54 55 55 55 55
  15   50 50 51 51 51 50 50 50 49 48 47 46 44 43 42 41 41 40 40 40 41 41 42 43 44 46 47 48 49 50 50 50 51 51 51 50 50
  20   48 48 48 48 48 47 47 46 46 45 43 42 41 39 38 37 36 35 35 35 36 37 38 39 41 42 43 45 46 46 47 47 48 48 48 48 48
  25   52 52 54 56 59 58 53 50 46 43 40 38 37 35 34 33 32 32 31 32 32 33 34 35 37 38 40 43 46 50 53 58 59 56 54 52 52
  30   37 37 37 38 39 40 40 41 41 40 37 35 33 32 31 30 30 29 29 29 30 30 31 32 33 35 37 40 41 41 40 40 39 38 37 37 37
  35   37 37 37 37 36 36 36 35 35 34 33 32 31 30 30 31 31 32 32 32 31 31 30 30 31 32 33 34 35 35 36 36 36 37 37 37 37
  40   42 42 44 45 44 42 40 37 34 31 30 31 34 37 35 32 30 29 29 29 30 32 35 37 34 31 30 31 34 37 40 42 44 45 44 42 42
  45   31 31 31 31 31 31 32 36 39 32 29 32 43 25 20 17 16 15 15 15 16 17 20 25 43 32 29 32 39 36 32 31 31 31 31 31 31
  50   29 30 31 31 30 28 27 28 35 36 29 32 27 17 12  9  8  8  8  8  8  9 12 17 27 32 29 36 35 28 27 28 30 31 31 30 29
  55   25 26 27 30 35 32 27 26 30 43 27 29 24 13  7  5  4  3  4  3  4  5  7 13 24 29 27 43 30 26 27 32 35 30 27 26 25
  60   24 24 25 27 30 39 33 28 29 42 27 27 25 12  6  3  2  2  2  2  2  3  6 12 25 27 27 42 29 28 33 39 30 27 25 24 24
  65   28 28 28 28 30 34 48 37 35 45 30 29 26 13  7  3  2  2  2  2  2  3  7 13 26 29 30 45 35 37 48 34 30 28 28 28 28
  70   35 35 34 33 33 35 39 40 36 40 37 38 24 13  7  4  2  2  2  2  2  4  7 13 24 38 37 40 36 40 39 35 33 33 34 35 35
  75   38 38 36 34 33 34 40 36 30 32 43 30 25 13  6  2  1  1  1  1  1  2  6 13 25 30 43 32 30 36 40 34 33 34 36 38 38
  80   45 44 40 36 34 34 39 41 32 32 40 32 27 13  6  2  1  1  1  1  1  2  6 13 27 32 40 32 32 41 39 34 34 36 40 44 45
  85   59 53 45 39 36 34 36 42 35 31 32 39 23 13  7  3  1  1  1  1  1  3  7 13 23 39 32 31 35 42 36 34 36 39 45 53 59
  90  136 59 47 40 36 34 35 38 33 29 30 32 21 13  7  3  1  0  0  0  1  3  7 13 21 32 30 29 33 38 35 34 36 40 47 59136
  95   59 53 45 39 36 34 36 42 35 31 32 39 23 13  7  3  1  1  1  1  1  3  7 13 23 39 32 31 35 42 36 34 36 39 45 53 59
 100   45 44 40 36 34 34 39 41 32 32 40 32 27 13  6  2  1  1  1  1  1  2  6 13 27 32 40 32 32 41 39 34 34 36 40 44 45
 105   38 38 36 34 33 34 40 36 30 32 43 30 25 13  6  2  1  1  1  1  1  2  6 13 25 30 43 32 30 36 40 34 33 34 36 38 38
 110   35 35 34 33 33 35 39 40 36 40 37 38 24 13  7  4  2  2  2  2  2  4  7 13 24 38 37 40 36 40 39 35 33 33 34 35 35
 115   28 28 28 28 30 34 48 37 35 45 30 29 26 13  7  3  2  2  2  2  2  3  7 13 26 29 30 45 35 37 48 34 30 28 28 28 28
 120   24 24 25 27 30 39 33 28 29 42 27 27 25 12  6  3  2  2  2  2  2  3  6 12 25 27 27 42 29 28 33 39 30 27 25 24 24
 125   25 26 27 30 35 32 27 26 30 43 27 29 24 13  7  5  4  3  4  3  4  5  7 13 24 29 27 43 30 26 27 32 35 30 27 26 25
 130   29 30 31 31 30 28 27 28 35 36 29 32 27 17 12  9  8  8  8  8  8  9 12 17 27 32 29 36 35 28 27 28 30 31 31 30 29
 135   31 31 31 31 31 31 32 36 39 32 29 32 43 25 20 17 16 15 15 15 16 17 20 25 43 32 29 32 39 36 32 31 31 31 31 31 31
 140   42 42 44 45 44 42 40 37 34 31 30 31 34 37 35 32 30 29 29 29 30 32 35 37 34 31 30 31 34 37 40 42 44 45 44 42 42
 145   37 37 37 37 36 36 36 35 35 34 33 32 31 30 30 31 31 32 32 32 31 31 30 30 31 32 33 34 35 35 36 36 36 37 37 37 37
 150   37 37 37 38 39 40 40 41 41 40 37 35 33 32 31 30 30 29 29 29 30 30 31 32 33 35 37 40 41 41 40 40 39 38 37 37 37
 155   52 52 54 56 59 58 53 50 46 43 40 38 37 35 34 33 32 32 31 32 32 33 34 35 37 38 40 43 46 50 53 58 59 56 54 52 52
 160   48 48 48 48 48 47 47 46 46 45 43 42 41 39 38 37 36 35 35 35 36 37 38 39 41 42 43 45 46 46 47 47 48 48 48 48 48
 165   50 50 51 51 51 50 50 50 49 48 47 46 44 43 42 41 41 40 40 40 41 41 42 43 44 46 47 48 49 50 50 50 51 51 51 50 50
 170   55 55 55 55 54 54 53 53 52 51 51 50 49 49 48 48 47 47 47 47 47 48 48 49 49 50 51 51 52 53 53 54 54 55 55 55 55
 175   61 61 61 61 61 61 61 61 60 60 60 60 60 60 59 59 59 59 59 59 59 59 59 60 60 60 60 60 60 61 61 61 61 61 61 61 61
 180  131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131

              GAIN DEGRADATION IS
                 -8.444
```

Figure 4.11
Pattern 5. Design Solution
Contour Plot

TABLE 4.1

Pattern 1. Amplitude and Phase settings.

Design Problem Solution Vector.

Element Number	A_i	α_i
1	1.00000	45.08598
2	0.83026	50.47632
3	0.55588	61.58244
4	0.28236	81.43579
5	0.14425	125.26320
6	0.73256	29.22868
7	0.55325	40.92334
8	0.36320	46.62827
9	0.17836	86.20399
10	0.00016	-23.47665
11	0.47729	5.06743
12	0.31261	4.35339
13	0.16010	7.01000
14	0.06544	-72.95085
15	0.03629	-110.93900
16	0.35335	-27.58368
17	0.24252	-58.43025
18	0.18708	-57.70381
19	0.00300	-96.97165
20	0.05679	-95.49803
21	0.19194	-79.03387
22	0.16094	-56.59669
23	0.09302	-116.47880
24	0.02788	-106.64440
25	0.01390	-153.24800

TABLE 4.2

Pattern 2. Amplitude and Phase settings.

Design Problem Solution Vector.

Element Number	A_i	α_i
1	1.00000	86.59134
2	0.72492	76.29446
3	0.40101	46.41832
4	0.21527	-16.98532
5	0.16095	-59.23582
6	0.67942	81.91975
7	0.49048	63.05440
8	0.23734	18.64299
9	0.24548	-33.18059
10	0.13429	-52.38556
11	0.24719	58.71460
12	0.21164	19.38586
13	0.27099	-8.95276
14	0.21564	-35.90080
15	0.13460	-62.06729
16	0.14507	-31.14095
17	0.14949	-28.63022
18	0.21673	-37.39592
19	0.14453	-54.42915
20	0.02817	-68.23637
21	0.13854	-65.68265
22	0.11909	-53.94441
23	0.06781	-47.95035
24	0.07849	-64.44748
25	0.00075	-78.08585

TABLE 4.3

Pattern 3. Amplitude and Phase settings.

Design Problem Solution Vector.

Element Number	A_i	α_i
1	1.00000	86.58992
2	0.72632	76.29305
3	0.34581	51.41776
4	0.23573	-21.98474
5	0.14923	-43.99036
6	0.69419	81.91833
7	0.47213	63.05298
8	0.24763	18.64278
9	0.23630	-30.62059
10	0.15778	-61.38362
11	0.24962	58.71346
12	0.19205	21.43350
13	0.26085	-8.95269
14	0.20757	-40.90024
15	0.10105	-52.45972
16	0.14143	-34.98846
17	0.14389	-26.19022
18	0.20862	-37.39572
19	0.13913	-49.42932
20	0.05563	-57.98967
21	0.11944	-68.87962
22	0.11464	-57.30469
23	0.06528	-43.59050
24	0.07555	-50.84010
25	0.00073	-73.46278

TABLE 4.4

Pattern 4. Amplitude and Phase settings.

Design Problem Solution Vector.

Element Number	A_i	α_i
1	1.00000	83.71129
2	0.58462	74.89516
3	0.14241	34.26509
4	0.19317	-61.69458
5	0.10087	-100.38940
6	0.55779	84.17863
7	0.34828	59.88213
8	0.23030	6.18118
9	0.18049	-23.08340
10	0.10228	-77.36714
11	0.00410	-174.76480
12	0.14119	-0.87991
13	0.26177	5.56305
14	0.19908	-13.63951
15	0.08626	-12.35343
16	0.15645	-99.23828
17	0.10658	-45.02731
18	0.16667	-6.84196
19	0.14051	1.34623
20	0.01905	-10.38139
21	0.08704	-100.32360
22	0.03587	-78.75728
23	0.03556	-40.04144
24	0.02226	115.26540
25	0.01850	89.00087

TABLE 4.5

Pattern 5. Amplitude and Phase settings.

Design Problem Solution Vector.

Element Number	A_i	α_i
1	0.66059	102.85650
2	0.38303	110.02400
3	0.01744	105.41250
4	0.09856	-85.83286
5	0.07641	-48.83804
6	1.00000	41.89236
7	0.65056	37.02228
8	0.17021	38.25259
9	0.08036	-93.32645
10	0.14957	-147.13670
11	0.81610	2.49893
12	0.47947	1.34707
13	0.17213	-20.41713
14	0.07275	-167.79430
15	0.06579	-165.56710
16	0.53865	-75.06853
17	0.36734	-77.70242
18	0.12291	-93.52895
19	0.00422	63.56360
20	0.08095	68.92059
21	0.27639	-101.25180
22	0.17685	-107.32960
23	0.05861	-94.70036
24	0.05308	43.36661
25	0.03110	53.67607

For each pattern, sensitivity values were determined for:

1. The main beam,
2. the two highest side lobes,
3. nulls if present,

at ± 1 percent and ± 2 percent error in A_i and α_i values, and at -2 percent, -1 percent, 1 percent and 2 percent error in λ. Because of the symmetry inherent in the pattern, a side lobe or null in one orthont will have an identical counterpart in the other three. For convenience, a set of four such symmetrical features will be referenced only in the orthont defined by:

$$0 \leq \theta \leq 90 \quad \text{and} \quad 0 \leq \phi \leq 90$$

The process by which the sensitivity values were obtained is described in detail for pattern 1. It holds for the other four patterns as well.

4.4 The MAXIM Runs

Four major features were identified. These are the main beam, the two highest side lobes , denoted sl(1) and sl(2), and the nulls. These features are outlined in figure 4.2.

The sensitivity of each of these features to error in A_i and α_i was analyzed separately, using MAXIM. Thus two MAXIM runs were made for each feature, with error ranges for A_i and α_i set first at 1 percent, and then at 2 percent. A_i and α_i vary independently, and the capability to model this is built into MAXIM. Setting these error ranges equal reflects a desire to keep the analysis as simple as possible.

Since MAXIM evaluates the directivity pattern, rather than the response surface, it is necessary to develop a set of goals which will

drive the solution to the minimum elevation point on the error surface. Directional response values which correspond to extreme degradation are therefore specified at a number of θ, ϕ points in the feature. It was felt that a 5-degree resolution was sufficient to define the features examined here. Smaller, irregularly shaped features may require a finer resolution. The goals are of the form:

$$G_{\theta\phi} + n_{\theta\phi} - p_{\theta\phi} = B_{\theta\phi}$$

where:

$G_{\theta\phi}$ is the directivity function for θ,ϕ.

$n_{\theta\phi}$ is a negative deviation variable.

$p_{\theta\phi}$ is a positive deviation variable.

$B_{\theta\phi}$ is a value representing the worst possible response at θ,ϕ in dB.

For θ,ϕ in the main beam, $B_{\theta\phi} = -60$ dB. For θ,ϕ in the side lobes or nulls, $B_{\theta\phi} = 1$ dB.

The objective function of MAXIM is of the form:

$$\text{MIN } Z = \sum_{\theta\phi} W_{\theta\phi} P_{\theta\phi}$$

for θ,ϕ in the main beam.

and

$$\text{MIN } Z = \sum_{\theta\phi} W_{\theta\phi} n_{\theta\phi}$$

for θ, ϕ in a side lobe or null

where the weighting factors, $W_{\theta\phi}$, are set to unity, indicating no difference in priority between θ, ϕ points in the same feature. This is the basic goal programming formulation in one priority level. There are, in fact, three priority levels in the problem, but two of these, excitation symmetry and error range, are implicit in the directivity function and pattern search logic respectively.

The solution vector of the design problem was used as the initial base point for the pattern search.

4.5 Sensitivity Values

MAXIM generates a contour plot, displaying the worst possible response of the given feature on a specified error region. This is then compared with the contour plot of the design solution directivity pattern, previously generated by NLGP. Two sensitivity values are taken for each MAXIM contour plot, i.e., for each feature at each error range. These are the average difference ($\overline{\Delta G}$), and the difference in the worst directional response values for any θ, ϕ point in the feature, (ΔGmax).

$\overline{\Delta G}$ is given by:

$$\sum_{\theta\phi} \frac{(G_{\theta\phi} - G'_{\theta\phi})}{n}$$

for θ, ϕ points in a side lobe or null. Or:

$$\sum_{\theta\phi} \frac{(G'_{\theta\phi} - G_{\theta\phi})}{n}$$

for θ, ϕ points in the main beam.

Where

$G_{\theta\phi}$ = the response at θ,ϕ for the design solution.

$G'_{\theta\phi}$ = the worst response at θ,ϕ in the error region.

n = the number of θ,ϕ points used to define the feature.

ΔGmax is given by:

$$M - M'$$

Where

M = Max $[G_{\theta\phi}]$ for θ,ϕ in a side lobe or null.

Min $[G_{\theta\phi}]$ for θ,ϕ in the main beam.

M' = Max $[G'_{\theta\phi}]$ for θ,ϕ in a side lobe or null.

Min $[G'_{\theta\phi}]$ for θ,ϕ in the main beam.

A negative value for $\overline{\Delta G}$ or ΔGmax indicates that the error has produced an improvement in the feature. This will not occur due to error in A_i and α_i, but may for error in λ.

4.6 Measurement of Operating Wavelength Error Impact

The designs were synthesized using an operating wavelength (λ) of 1 unit length. In order to determine sensitivity to error in λ, patterns were made for each design where all element amplitude and phase settings were maintained at the design solution values, and operating wavelength was set at .98, .99, 1.01, and 1.02 units of length. The two sensitivity measures defined above, $\overline{\Delta G}$ and Δ Gmax, were then measured on each feature.

4.7 Results

Figures 4.12 to 4.45 are contour plots of patterns 1 through 5, showing the maximum impacts of 1 and 2 percent error in amplitude and phase settings on the features outlined.

Figures 4.46 to 4.50 are graphs of feature sensitivity to error in A_i and α_i, measured in terms of $\overline{\Delta G}$ for each pattern. Figures 4.51 to 4.55 are graphs of feature sensitivity to error in A_i and α_i, measured in terms of ΔGmax for each pattern.

Figures 4.56 and 4.57 are graphs of main beam sensitivity to error in A_i and α_i, across the 5 patterns, measured in terms of $\overline{\Delta G}$, and ΔGmax respectively. Figures 4.58 and 4.59 are graphs of aggregated side lobe sensitivity to error in A_i and α_i across the 5 patterns, measured in terms of $\overline{\Delta G}$, and ΔGmax respectively.

Tables 4.6 to 4.39 show the amplitude and phase values for each pattern generated by MAXIM.

Table 4.40 summarizes the data for amplitude and phase error sensitivity. Table 4.42 presents the data for operating wavelength sensitivity. As the figures indicate that sensitivity to $\leq$ 2 percent absolute error in λ is quite low, it was felt that little information was to be gained by the presentation of the associated contour plots.

```
          BORESIGHT AT 90,90

THETA                        PHI

          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0   131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131
   5    58 58 58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58 58 58
  10    52 52 52 51 51 50 50 49 49 48 48 47 46 46 46 45 45 45 45 45 45 45 46 46 46 47 48 48 49 49 50 50 51 51 52 52 52
  15    61 61 60 58 56 54 52 50 48 46 45 43 42 41 40 39 39 38 38 38 39 39 40 41 42 43 45 46 48 50 52 54 56 58 60 61 61
  20    50 50 50 50 51 51 53 55 57 54 49 45 42 39 37 36 35 34 34 34 35 36 37 39 42 45 49 54 57 55 53 51 51 50 50 50 50
  25    40 40 40 41 42 43 43 43 44 44 46 48 46 41 38 35 33 32 32 32 33 35 38 41 46 48 46 44 44 43 43 43 42 41 40 40 40
  30    31 31 31 32 33 35 37 39 39 38 37 37 38 39 38 35 33 31 31 31 33 35 38 39 38 37 37 38 39 39 37 35 33 32 31 31 31
  35    28 28 28 28 29 30 32 34 36 36 34 32 32 32 32 32 31 30 29 30 31 32 32 32 32 32 34 36 36 34 32 30 29 28 28 28 28
  40    32 32 32 31 31 31 32 34 37 38 34 30 29 28 28 28 28 27 27 27 28 28 28 28 29 30 34 38 37 34 32 31 31 31 32 32 32
  45    35 35 35 34 34 33 34 36 43 45 35 30 28 27 27 27 27 27 27 27 27 27 27 27 28 30 35 45 43 36 34 33 34 34 35 35 35
  50    33 33 32 31 31 30 30 30 31 32 32 30 29 30 31 31 32 34 35 34 32 31 31 30 29 30 32 32 31 30 30 30 31 31 32 33 33
  55    64 63 53 46 40 36 34 32 31 30 29 29 31 37 35 30 29 31 32 31 29 30 35 37 31 29 29 30 31 32 34 36 40 46 53 63 64
  60    31 31 31 32 32 34 36 44 47 35 31 30 33 44 29 27 30 35 33 35 30 27 29 44 33 30 31 35 47 44 36 34 32 32 31 31 31
  65    30 29 29 28 28 28 29 30 32 37 36 33 34 32 28 33 26 18 16 18 26 33 28 32 34 33 36 37 32 30 29 28 28 28 29 29 30
  70    33 33 32 31 30 30 30 32 32 33 35 33 30 27 30 26 15 10  8 10 15 26 30 27 30 33 35 33 32 32 30 30 30 31 32 33 33
  75    42 41 39 37 36 36 40 65 38 35 36 33 28 27 34 19 10  6  4  6 10 19 34 27 28 33 36 35 38 65 40 36 36 37 39 41 42
  80    68 66 62 56 50 43 37 33 31 31 37 41 30 27 21 13  7  3  2  3  7 13 21 27 30 41 37 31 31 33 37 43 50 56 62 66 68
  85    60 54 46 40 36 33 31 29 29 29 31 34 36 25 15  9  4  2  1  2  4  9 15 25 36 34 31 29 29 29 31 33 36 40 46 54 60
  90   126 56 44 37 33 30 28 28 29 29 29 31 41 23 14  7  3  1  0  1  3  7 14 23 41 31 29 29 29 28 28 30 33 37 44 56126
  95    60 54 46 40 36 33 31 29 29 29 31 34 36 25 15  9  4  2  1  2  4  9 15 25 36 34 31 29 29 29 31 33 36 40 46 54 60
 100    68 66 62 56 50 43 37 33 31 31 37 41 30 27 21 13  7  3  2  3  7 13 21 27 30 41 37 31 31 33 37 43 50 56 62 66 68
 105    42 41 39 37 36 36 40 65 38 35 36 33 28 27 34 19 10  6  4  6 10 19 34 27 28 33 36 35 38 65 40 36 36 37 39 41 42
 110    33 33 32 31 30 30 30 32 32 33 35 33 30 27 30 26 15 10  8 10 15 26 30 27 30 33 35 33 32 32 30 30 30 31 32 33 33
 115    30 29 29 28 28 28 29 30 32 37 36 33 34 32 28 33 26 18 16 18 26 33 28 32 34 33 36 37 32 30 29 28 28 28 29 29 30
 120    31 31 31 32 32 34 36 44 47 35 31 30 33 44 29 27 30 35 33 35 30 27 29 44 33 30 31 35 47 44 36 34 32 32 31 31 31
 125    64 63 53 46 40 36 34 32 31 30 29 29 31 37 35 30 29 31 32 31 29 30 35 37 31 29 29 30 31 32 34 36 40 46 53 63 64
 130    33 33 32 31 31 30 30 30 31 32 32 30 29 30 31 31 32 34 35 34 32 31 31 30 29 30 32 32 31 30 30 30 31 31 32 33 33
 135    35 35 35 34 34 33 34 36 43 45 35 30 28 27 27 27 27 27 27 27 27 27 27 27 28 30 35 45 43 36 34 33 34 34 35 35 35
 140    32 32 32 31 31 31 32 34 37 38 34 30 29 28 28 28 28 27 27 27 28 28 28 28 29 30 34 38 37 34 32 31 31 31 32 32 32
 145    28 28 28 28 29 30 32 34 36 36 34 32 32 32 32 32 31 30 29 30 31 32 32 32 32 32 34 36 36 34 32 30 29 28 28 28 28
 150    31 31 31 32 33 35 37 39 39 38 37 37 38 39 38 35 33 31 31 31 33 35 38 39 38 37 37 38 39 39 37 35 33 32 31 31 31
 155    40 40 40 41 42 43 43 43 43 44 46 48 46 41 38 35 33 32 32 32 33 35 38 41 46 48 46 44 43 43 43 43 42 41 40 40 40
 160    50 50 50 50 51 51 53 55 57 54 49 45 42 39 37 36 35 34 34 34 35 36 37 39 42 45 49 54 57 55 53 51 51 50 50 50 50
 165    61 61 60 58 56 54 52 50 48 46 45 43 42 41 40 39 39 38 38 38 39 39 40 41 42 43 45 46 48 50 52 54 56 58 60 61 61
 170    52 52 52 51 51 50 50 49 49 48 48 47 46 46 46 45 45 45 45 45 45 45 46 46 46 47 48 48 49 49 50 50 51 51 52 52 52
 175    58 58 58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58 58 58
 180   131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131131

              GAIN DEGRADATION IS
                -6.148
```

Figure 4.12
Pattern 1. 1 Percent Error
Maximum Impact on The Main Beam

```
           BORESIGHT AT 90,90
THETA                                      PHI
         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0     130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130
  5      59 59 59 59 59 59 59 59 59 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 59 59 59 59 59 59 59 59 59
 10      52 52 52 52 51 51 50 50 49 49 48 48 47 47 46 46 46 46 46 46 46 46 46 47 47 48 48 49 49 50 50 51 51 52 52 52 52
 15      53 53 53 53 52 51 50 49 48 46 45 44 42 41 40 40 39 39 39 39 39 40 40 41 42 44 45 46 48 49 50 51 52 53 53 53 53
 20      48 48 48 48 48 48 48 48 47 47 45 43 41 39 37 36 35 34 34 34 35 36 37 39 41 43 45 47 47 48 48 48 48 48 48 48 48
 25      40 41 41 42 43 44 43 42 42 41 41 41 40 38 35 33 32 31 31 31 32 33 35 38 40 41 41 41 42 42 43 44 43 42 41 41 40
 30      31 31 31 32 34 35 38 39 39 37 36 35 35 34 33 31 30 29 28 29 30 31 33 34 35 35 36 37 39 39 38 35 34 32 31 31 31
 35      28 28 28 28 29 30 32 35 37 36 33 31 30 30 29 28 27 26 26 26 27 28 29 30 30 31 33 36 37 35 32 30 29 28 28 28 28
 40      33 32 32 31 31 31 32 34 37 37 33 30 28 27 26 26 26 26 25 26 26 26 26 27 28 30 33 37 37 34 32 31 31 31 32 32 33
 45      35 35 35 34 33 33 34 36 44 42 33 29 27 26 26 26 26 26 26 26 26 26 26 26 27 29 33 42 44 36 34 33 33 34 35 35 35
 50      33 32 32 31 30 30 29 30 31 32 31 29 28 29 29 30 32 34 35 34 32 30 29 29 28 29 31 32 31 30 29 30 30 31 32 32 33
 55      54 52 48 43 39 35 33 31 30 29 28 28 30 35 34 30 29 31 32 31 29 30 34 35 30 28 28 29 30 31 33 35 39 43 48 52 54
 60      32 32 32 32 32 34 36 43 45 34 30 29 33 45 29 26 29 36 37 36 29 26 29 45 33 29 30 34 45 43 36 34 32 32 32 32 32
 65      30 30 29 28 28 28 28 30 33 38 37 34 35 31 27 30 28 20 17 20 28 30 27 31 35 34 37 38 33 30 28 28 28 28 29 30 30
 70      33 33 32 30 29 29 29 31 32 34 36 34 30 27 28 29 16 11  9 11 16 29 28 27 30 34 36 34 32 31 29 29 29 30 32 33 33
 75      42 41 39 37 35 35 38 46 43 38 39 33 28 26 32 20 11  6  5  6 11 20 32 26 28 33 39 38 43 46 38 35 35 37 39 41 42
 80      63 61 57 52 47 43 38 34 32 32 37 41 30 26 21 13  7  4  2  4  7 13 21 26 30 41 37 32 32 34 38 43 47 52 57 61 63
 85      57 51 43 38 33 30 28 28 28 30 31 32 40 25 15  9  4  1  0  1  4  9 15 25 40 32 31 30 28 28 28 30 33 38 43 51 57
 90     124 54 42 36 31 28 26 26 28 30 29 29 43 23 14  7  3  1  0  1  3  7 14 23 43 29 29 30 28 26 26 28 31 36 42 54124
 95      57 51 43 38 33 30 28 28 28 30 31 32 40 25 15  9  4  1  0  1  4  9 15 25 40 32 31 30 28 28 28 30 33 38 43 51 57
100      63 61 57 52 47 43 38 34 32 32 37 41 30 26 21 13  7  4  2  4  7 13 21 26 30 41 37 32 32 34 38 43 47 52 57 61 63
105      42 41 39 37 35 35 38 46 43 38 39 33 28 26 32 20 11  6  5  6 11 20 32 26 28 33 39 38 43 46 38 35 35 37 39 41 42
110      33 33 32 30 29 29 29 31 32 34 36 34 30 27 28 29 16 11  9 11 16 29 28 27 30 34 36 34 32 31 29 29 29 30 32 33 33
115      30 30 29 28 28 28 28 30 33 38 37 34 35 31 27 30 28 20 17 20 28 30 27 31 35 34 37 38 33 30 28 28 28 28 29 30 30
120      32 32 32 32 32 34 36 43 45 34 30 29 33 45 29 26 29 36 37 36 29 26 29 45 33 29 30 34 45 43 36 34 32 32 32 32 32
125      54 52 48 43 39 35 33 31 30 29 28 28 30 35 34 30 29 31 32 31 29 30 34 35 30 28 28 29 30 31 33 35 39 43 48 52 54
130      33 32 32 31 30 30 29 30 31 32 31 29 28 29 29 30 32 34 35 34 32 30 29 29 28 29 31 32 31 30 29 30 30 31 32 32 33
135      35 35 35 34 33 33 34 36 44 42 33 29 27 26 26 26 26 26 26 26 26 26 26 26 27 29 33 42 44 36 34 33 33 34 35 35 35
140      33 32 32 31 31 31 32 34 37 37 33 30 28 27 26 26 26 26 25 26 26 26 26 27 28 30 33 37 37 34 32 31 31 31 32 32 33
145      28 28 28 28 29 30 32 35 37 36 33 31 30 30 29 28 27 26 26 26 27 28 29 30 30 31 33 36 37 35 32 30 29 28 28 28 28
150      31 31 31 32 34 35 38 39 39 37 36 35 35 34 33 31 30 29 28 29 30 31 33 34 35 35 36 37 39 39 38 35 34 32 31 31 31
155      40 41 41 42 43 44 43 42 42 41 41 41 40 38 35 33 32 31 31 31 32 33 35 38 40 41 41 41 42 42 43 44 43 42 41 41 40
160      48 48 48 48 48 48 48 48 47 47 45 43 41 39 37 36 35 34 34 34 35 36 37 39 41 43 45 47 47 48 48 48 48 48 48 48 48
165      53 53 53 53 52 51 50 49 48 46 45 44 42 41 40 40 39 39 39 39 39 40 40 41 42 44 45 46 48 49 50 51 52 53 53 53 53
170      52 52 52 52 51 51 50 50 49 49 48 48 47 47 46 46 46 46 46 46 46 46 46 47 47 48 48 49 49 50 50 51 51 52 52 52 52
175      59 59 59 59 59 59 59 59 59 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 59 59 59 59 59 59 59 59 59
180     130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130

                    GAIN DEGRADATION IS
                      -0.055
```

Figure 4.13
Pattern 1. 2 Percent Error
Maximum Impact on the Main Beam

```
          BORESIGHT AT 90,90

THETA                                PHI

        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125
   5   56 56 56 56 56 56 55 55 55 55 55 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 55 55 55 55 55 56 56 56 56 56 56
  10   53 52 52 52 51 50 49 49 48 47 46 45 44 43 43 42 42 42 42 42 42 42 43 43 44 45 46 47 48 49 49 50 51 52 52 52 53
  15   66 66 66 65 64 61 57 54 50 47 45 42 40 39 37 36 36 35 35 35 36 36 37 39 40 42 45 47 50 54 57 61 64 65 66 66 66
  20   54 54 56 59 63 64 61 59 61 60 52 46 41 37 35 33 31 31 30 31 31 33 35 37 41 46 52 60 61 59 61 64 63 59 56 54 54
  25   36 36 37 38 39 41 44 47 47 45 44 44 42 38 34 31 29 28 27 28 29 31 34 38 42 44 44 45 47 47 44 41 39 38 37 36 36
  30   28 28 29 29 30 32 34 37 39 39 37 35 34 33 31 29 27 25 25 25 27 29 31 33 34 35 37 39 39 37 34 32 30 29 29 28 28
  35   26 26 26 26 27 28 29 31 34 36 34 31 29 27 27 25 25 24 23 24 25 25 27 27 29 31 34 36 34 31 29 28 27 26 26 26 26
  40   30 30 30 29 29 28 29 30 34 37 33 29 26 25 24 23 23 22 22 22 23 23 24 25 26 29 33 37 34 30 29 28 29 29 30 30 30
  45   33 33 33 32 31 31 31 32 36 57 36 29 25 24 23 23 23 23 23 23 23 23 23 24 25 29 36 57 36 32 31 31 31 32 33 33 33
  50   31 31 30 30 29 28 29 29 31 34 33 29 27 26 25 26 28 29 29 29 28 26 25 26 27 29 33 34 31 29 28 28 29 30 30 31 31
  55   64 59 49 43 38 34 32 30 30 30 30 29 29 32 33 34 37 32 30 32 37 34 33 32 29 29 30 30 30 30 32 34 38 43 49 59 64
  60   30 30 30 30 31 33 37 46 45 36 31 29 32 48 30 28 31 25 24 25 31 28 30 48 32 29 31 36 45 46 37 33 31 30 30 30 30
  65   28 28 27 27 27 27 28 29 31 35 34 30 31 31 28 35 22 15 13 15 22 35 28 31 31 30 34 35 31 29 28 27 27 27 27 28 28
  70   31 31 30 29 28 29 30 31 30 30 31 31 29 28 32 23 12  7  6  7 12 23 32 28 29 31 31 30 30 31 30 29 28 29 30 31 31
  75   39 38 36 34 33 33 37 48 33 30 31 31 28 29 33 16  8  4  2  4  8 16 33 29 28 31 31 30 33 48 37 33 33 34 36 38 39
  80   59 57 53 49 46 42 37 32 29 29 34 37 30 27 20 11  6  2  1  2  6 11 20 27 30 37 34 29 29 32 37 42 46 49 53 57 59
  85   60 54 46 40 36 34 32 31 29 28 30 37 32 24 14  8  4  1  0  1  4  8 14 24 32 37 30 28 29 31 32 34 36 40 46 54 60
  90  127 55 43 37 32 30 29 30 29 27 27 32 34 23 13  7  3  1  0  1  3  7 13 23 34 32 27 27 29 30 29 30 32 37 43 55127
  95   60 54 46 40 36 34 32 31 29 28 30 37 32 24 14  8  4  1  0  1  4  8 14 24 32 37 30 28 29 31 32 34 36 40 46 54 60
 100   59 57 53 49 46 42 37 32 29 29 34 37 30 27 20 11  6  2  1  2  6 11 20 27 30 37 34 29 29 32 37 42 46 49 53 57 59
 105   39 38 36 34 33 33 37 48 33 30 31 31 28 29 33 16  8  4  2  4  8 16 33 29 28 31 31 30 33 48 37 33 33 34 36 38 39
 110   31 31 30 29 28 29 30 31 30 30 31 31 29 28 32 23 12  7  6  7 12 23 32 28 29 31 31 30 30 31 30 29 28 29 30 31 31
 115   28 28 27 27 27 27 28 29 31 35 34 30 31 31 28 35 22 15 13 15 22 35 28 31 31 30 34 35 31 29 28 27 27 27 27 28 28
 120   30 30 30 30 31 33 37 46 45 36 31 29 32 48 30 28 31 25 24 25 31 28 30 48 32 29 31 36 45 46 37 33 31 30 30 30 30
 125   64 59 49 43 38 34 32 30 30 30 30 29 29 32 33 34 37 32 30 32 37 34 33 32 29 29 30 30 30 30 32 34 38 43 49 59 64
 130   31 31 30 30 29 28 28 29 31 34 33 29 27 26 25 26 28 29 29 29 28 26 25 26 27 29 33 34 31 29 28 28 29 30 30 31 31
 135   33 33 33 32 31 31 31 32 36 57 36 29 25 24 23 23 23 23 23 23 23 23 23 24 25 29 36 57 36 32 31 31 31 32 33 33 33
 140   30 30 30 29 29 28 29 30 34 37 33 29 26 25 24 23 23 22 22 22 23 23 24 25 26 29 33 37 34 30 29 28 29 29 30 30 30
 145   26 26 26 26 27 28 29 31 34 36 34 31 29 27 27 25 25 24 23 24 25 25 27 27 29 31 34 36 34 31 29 28 27 26 26 26 26
 150   28 28 29 29 30 32 34 37 39 39 37 35 34 33 31 29 27 25 25 25 27 29 31 33 34 35 37 39 39 37 34 32 30 29 29 28 28
 155   36 36 37 38 39 41 44 47 47 45 44 44 42 38 34 31 29 28 27 28 29 31 34 38 42 44 44 45 47 47 44 41 39 38 37 36 36
 160   54 54 56 59 63 64 61 59 61 60 52 46 41 37 35 33 31 31 30 31 31 33 35 37 41 46 52 60 61 59 61 64 63 59 56 54 54
 165   66 66 66 65 64 61 57 54 50 47 45 42 40 39 37 36 36 35 35 35 36 36 37 39 40 42 45 47 50 54 57 61 64 65 66 66 66
 170   53 52 52 52 51 50 49 49 48 47 46 45 44 43 43 42 42 42 42 42 42 42 43 43 44 45 46 47 48 49 49 50 51 52 52 52 53
 175   56 56 56 56 56 56 55 55 55 55 55 54 54 54 54 54 54 54 54 54 54 54 54 54 54 54 55 55 55 55 55 56 56 56 56 56 56
 180  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125

              GAIN DEGRADATION IS
                 -8.319
```

Figure 4.14
Pattern 1. 1 Percent Error
Maximum Impact on Side Lobe 1

```
          BORESIGHT AT 90,90

THETA                              PHI

        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0    121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121
  5     53 53 53 53 53 53 52 52 52 52 52 52 52 51 51 51 51 51 51 51 51 51 51 51 52 52 52 52 52 52 52 53 53 53 53 53 53
 10     46 46 46 46 45 45 44 44 43 43 42 41 41 40 40 40 39 39 39 39 39 40 40 40 41 41 42 43 43 44 44 45 45 46 46 46 46
 15     46 46 46 45 45 44 43 42 41 40 38 37 36 35 34 33 33 32 32 32 33 33 34 35 36 37 38 40 41 42 43 44 45 45 46 46 46
 20     46 46 46 45 45 44 43 41 40 39 37 35 33 32 30 29 28 28 27 28 28 29 30 32 33 35 37 39 40 41 43 44 45 45 46 46 46
 25     36 36 36 37 39 40 41 41 39 36 35 33 31 29 27 26 25 25 25 25 25 26 27 29 31 33 35 36 39 41 41 40 39 37 36 36 36
 30     28 28 29 29 30 32 35 38 39 35 32 29 28 26 25 24 23 22 22 22 23 24 25 26 28 29 32 35 39 38 35 32 30 29 29 28 28
 35     26 26 26 26 27 27 29 32 38 38 31 27 25 24 23 21 21 20 20 20 21 21 23 24 25 27 31 38 38 32 29 27 27 26 26 26 26
 40     30 29 29 28 27 27 28 29 33 51 33 26 24 21 20 20 19 19 19 19 19 20 20 21 24 26 33 51 33 29 28 27 27 28 29 29 30
 45     38 38 36 34 32 30 29 29 31 35 35 27 24 21 20 19 20 20 20 20 20 19 20 21 24 27 35 35 31 29 29 30 32 34 36 38 38
 50     35 35 34 33 32 31 30 29 30 31 31 28 25 23 22 22 24 25 25 25 24 22 22 23 25 28 31 31 30 29 30 31 32 33 34 35 35
 55     44 44 46 49 45 39 35 32 31 30 30 29 28 28 29 33 34 28 26 28 34 33 29 28 28 29 30 30 31 32 35 39 45 49 46 44 44
 60     29 29 29 29 30 31 34 41 42 34 31 31 35 47 34 32 28 23 22 23 28 32 34 47 35 31 31 34 42 41 34 31 30 29 29 29 29
 65     28 28 28 27 27 27 27 28 31 34 33 32 34 31 28 31 20 14 12 14 20 31 28 31 34 32 33 34 31 28 27 27 27 27 28 28 28
 70     34 33 32 31 30 30 30 30 29 29 31 31 30 29 33 22 12  7  5  7 12 22 33 29 30 31 31 29 29 30 30 30 30 31 32 33 34
 75     41 41 39 37 36 37 42 40 32 30 30 30 29 31 30 16  8  4  2  4  8 16 30 31 29 30 30 30 32 40 42 37 36 37 39 41 41
 80     57 55 50 46 41 37 33 30 29 30 36 34 29 28 19 11  5  2  1  2  5 11 19 28 29 34 36 30 29 30 33 37 41 46 50 55 57
 85     57 51 43 38 34 31 30 29 27 27 29 36 30 24 14  8  4  1  1  1  4  8 14 24 30 36 29 27 27 29 30 31 34 38 43 51 57
 90    125 54 42 35 31 28 28 29 28 25 26 31 30 22 13  7  3  1  0  1  3  7 13 22 30 31 26 25 28 29 28 28 31 35 42 54125
 95     57 51 43 38 34 31 30 29 27 27 29 36 30 24 14  8  4  1  1  1  4  8 14 24 30 36 29 27 27 29 30 31 34 38 43 51 57
100     57 55 50 46 41 37 33 30 29 30 36 34 29 28 19 11  5  2  1  2  5 11 19 28 29 34 36 30 29 30 33 37 41 46 50 55 57
105     41 41 39 37 36 37 42 40 32 30 30 30 29 31 30 16  8  4  2  4  8 16 30 31 29 30 30 30 32 40 42 37 36 37 39 41 41
110     34 33 32 31 30 30 30 30 29 29 31 31 30 29 33 22 12  7  5  7 12 22 33 29 30 31 31 29 29 30 30 30 30 31 32 33 34
115     28 28 28 27 27 27 27 28 31 34 33 32 34 31 28 31 20 14 12 14 20 31 28 31 34 32 33 34 31 28 27 27 27 27 28 28 28
120     29 29 29 29 30 31 34 41 42 34 31 31 35 47 34 32 28 23 22 23 28 32 34 47 35 31 31 34 42 41 34 31 30 29 29 29 29
125     44 44 46 49 45 39 35 32 31 30 30 29 28 28 29 33 34 28 26 28 34 33 29 28 28 29 30 30 31 32 35 39 45 49 46 44 44
130     35 35 34 33 32 31 30 29 30 31 31 28 25 23 22 22 24 25 25 25 24 22 22 23 25 28 31 31 30 29 30 31 32 33 34 35 35
135     38 38 36 34 32 30 29 29 31 35 35 27 24 21 20 19 20 20 20 20 20 19 20 21 24 27 35 35 31 29 29 30 32 34 36 38 38
140     30 29 29 28 27 27 28 29 33 51 33 26 24 21 20 20 19 19 19 19 19 20 20 21 24 26 33 51 33 29 28 27 27 28 29 29 30
145     26 26 26 26 27 27 29 32 38 38 31 27 25 24 23 21 21 20 20 20 21 21 23 24 25 27 31 38 38 32 29 27 27 26 26 26 26
150     28 28 29 29 30 32 35 38 39 35 32 29 28 26 25 24 23 22 22 22 23 24 25 26 28 29 32 35 39 38 35 32 30 29 29 28 28
155     36 36 36 37 39 40 41 41 39 36 35 33 31 29 27 26 25 25 25 25 25 26 27 29 31 33 35 36 39 41 41 40 39 37 36 36 36
160     46 46 46 45 45 44 43 41 40 39 37 35 33 32 30 29 28 28 27 28 28 29 30 32 33 35 37 39 40 41 43 44 45 45 46 46 46
165     46 46 46 45 45 44 43 42 41 40 38 37 36 35 34 33 33 32 32 32 33 33 34 35 36 37 38 40 41 42 43 44 45 45 46 46 46
170     46 46 46 46 45 45 44 44 43 43 42 41 41 40 40 40 39 39 39 39 39 40 40 40 41 41 42 43 43 44 44 45 45 46 46 46 46
175     53 53 53 53 53 53 52 52 52 52 52 52 52 51 51 51 51 51 51 51 51 51 51 51 52 52 52 52 52 52 52 53 53 53 53 53 53
180    121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121

                   GAIN DEGRADATION IS
                     -0.394
```

Figure 4.15
Pattern 1. 2 Percent Error
Maximum Impact on Side Lobe 1

```
           BORESIGHT AT 90,30

THETA                                    PHI

         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125
    5   54 54 54 54 54 54 54 54 54 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 54 54 54 54 54 54 54 54 54
   10   48 48 47 47 47 46 46 45 45 44 44 43 42 42 41 41 41 41 41 41 41 41 41 42 42 43 44 44 45 45 46 46 47 47 47 48 48
   15   48 48 47 47 47 46 45 44 43 42 41 39 38 37 36 35 34 34 34 34 34 35 36 37 38 39 41 42 43 44 45 46 47 47 47 48 48
   20   52 52 51 49 48 47 46 45 44 43 42 39 37 35 33 32 31 30 30 30 31 32 33 35 37 39 42 43 44 45 46 47 48 49 51 52 52
   25   40 41 42 43 47 53 56 49 45 43 43 43 41 37 34 31 29 28 28 28 29 31 34 37 41 43 43 43 45 49 56 53 47 43 42 41 40
   30   30 30 30 31 32 34 37 42 47 44 40 40 41 46 42 35 31 29 28 29 31 35 42 46 41 40 40 44 47 42 37 34 32 31 30 30 30
   35   27 27 27 27 28 29 30 33 37 41 39 36 34 35 38 45 39 34 33 34 39 45 38 35 34 36 39 41 37 33 30 29 28 27 27 27 27
   40   32 32 31 31 30 30 30 32 34 40 39 34 31 30 30 31 33 34 35 34 33 31 30 30 31 34 39 40 34 32 30 30 30 31 31 32 32
   45   34 34 33 33 33 32 33 34 37 46 44 35 32 30 29 29 29 30 30 30 29 29 29 30 32 35 44 46 37 34 33 32 33 33 33 34 34
   50   30 30 29 29 28 28 28 28 30 32 34 34 34 33 32 30 28 28 28 28 28 30 32 33 34 34 34 32 30 28 28 28 28 29 29 30 30
   55   40 39 38 36 34 31 29 28 28 28 30 32 36 37 30 26 25 25 25 25 25 26 30 37 36 32 30 28 28 28 29 31 34 36 38 39 40
   60   31 31 31 31 32 33 35 37 36 34 32 33 42 34 26 25 28 33 32 33 28 25 26 34 42 33 32 34 36 37 35 33 32 31 31 31 31
   65   30 30 29 28 28 28 28 29 30 33 41 39 35 29 26 34 24 16 14 16 24 34 26 29 35 39 41 33 30 29 28 28 28 28 29 30 30
   70   34 34 33 32 32 32 33 31 28 27 28 29 28 26 28 25 13  8  6  8 13 25 28 26 28 29 28 27 28 31 33 32 32 32 33 34 34
   75   40 40 38 36 35 35 36 34 29 27 28 28 26 25 31 17  8  4  3  4  8 17 31 25 26 28 28 27 29 34 36 35 35 36 38 40 40
   80   48 46 42 38 34 30 27 25 25 25 30 37 28 25 20 12  6  2  1  2  6 12 20 25 28 37 30 25 25 25 27 30 34 38 42 46 48
   85   53 47 40 34 29 26 25 23 22 23 25 31 37 25 14  8  3  1  0  1  3  8 14 25 37 31 25 23 22 23 25 26 29 34 40 47 53
   90  121 51 39 32 27 25 23 22 22 22 23 27 41 23 13  6  2  0  0  0  2  6 13 23 41 27 23 22 22 22 23 25 27 32 39 51121
   95   53 47 40 34 29 26 25 23 22 23 25 31 37 25 14  8  3  1  0  1  3  8 14 25 37 31 25 23 22 23 25 26 29 34 40 47 53
  100   48 46 42 38 34 30 27 25 25 25 30 37 28 25 20 12  6  2  1  2  6 12 20 25 28 37 30 25 25 25 27 30 34 38 42 46 48
  105   40 40 38 36 35 35 36 34 29 27 28 28 26 25 31 17  8  4  3  4  8 17 31 25 26 28 28 27 29 34 36 35 35 36 38 40 40
  110   34 34 33 32 32 32 33 31 28 27 28 29 28 26 28 25 13  8  6  8 13 25 28 26 28 29 28 27 28 31 33 32 32 32 33 34 34
  115   30 30 29 28 28 28 28 29 30 33 41 39 35 29 26 34 24 16 14 16 24 34 26 29 35 39 41 33 30 29 28 28 28 28 29 30 30
  120   31 31 31 31 32 33 35 37 36 34 32 33 42 34 26 25 28 33 32 33 28 25 26 34 42 33 32 34 36 37 35 33 32 31 31 31 31
  125   40 39 38 36 34 31 29 28 28 28 30 32 36 37 30 26 25 25 25 25 25 26 30 37 36 32 30 28 28 28 29 31 34 36 38 39 40
  130   30 30 29 29 28 28 28 28 30 32 34 34 34 33 32 30 28 28 28 28 28 30 32 33 34 34 34 32 30 28 28 28 28 29 29 30 30
  135   34 34 33 33 33 32 33 34 37 46 44 35 32 30 29 29 29 30 30 30 29 29 29 30 32 35 44 46 37 34 33 32 33 33 33 34 34
  140   32 32 31 31 30 30 30 32 34 40 39 34 31 30 30 31 33 34 35 34 33 31 30 30 31 34 39 40 34 32 30 30 30 31 31 32 32
  145   27 27 27 27 28 29 30 33 37 41 39 36 34 35 38 45 39 34 33 34 39 45 38 35 34 36 39 41 37 33 30 29 28 27 27 27 27
  150   30 30 30 31 32 34 37 42 47 44 40 40 41 46 42 35 31 29 28 29 31 35 42 46 41 40 40 44 47 42 37 34 32 31 30 30 30
  155   40 41 42 43 47 53 56 49 45 43 43 43 41 37 34 31 29 28 28 28 29 31 34 37 41 43 43 43 45 49 56 53 47 43 42 41 40
  160   52 52 51 49 48 47 46 45 44 43 42 39 37 35 33 32 31 30 30 30 31 32 33 35 37 39 42 43 44 45 46 47 48 49 51 52 52
  165   48 48 47 47 47 46 45 44 43 42 41 39 38 37 36 35 34 34 34 34 34 35 36 37 38 39 41 42 43 44 45 46 47 47 47 48 48
  170   48 48 47 47 47 46 46 45 45 44 44 43 42 42 41 41 41 41 41 41 41 41 41 42 42 43 44 44 45 45 46 46 47 47 47 48 48
  175   54 54 54 54 54 54 54 54 54 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 53 54 54 54 54 54 54 54 54 54
  180  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125

                   GAIN DEGRADATION IS
                     -8.269
```

Figure 4.16
Pattern 1. 1 Percent Error
Maximum Impact on Side Lobe 2

```
           BORESIGHT AT 90,90
THETA                                  PHI
        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125
    5   55 55 55 55 55 55 55 54 54 54 54 54 53 53 53 53 53 53 53 53 53 53 53 53 53 54 54 54 54 54 55 55 55 55 55 55 55
   10   50 50 50 50 49 49 48 47 46 45 45 44 43 42 42 41 41 41 41 41 41 41 42 42 43 44 45 45 46 47 48 49 49 50 50 50 50
   15   52 52 52 52 51 51 50 49 47 45 43 41 39 38 36 35 35 34 34 34 35 35 36 38 39 41 43 45 47 49 50 51 51 52 52 52 52
   20   68 67 63 59 55 53 51 50 50 49 48 44 40 37 34 32 31 30 30 30 31 32 34 37 40 44 48 49 50 50 51 53 55 59 63 67 68
   25   38 38 39 40 42 45 51 55 50 47 47 52 52 41 35 32 29 28 28 28 29 32 35 41 52 52 47 47 50 55 51 45 42 40 39 38 38
   30   29 29 30 30 31 33 35 39 44 43 40 39 39 42 39 33 29 27 27 27 29 33 39 42 39 39 40 43 44 39 35 33 31 30 30 29 29
   35   26 26 26 26 27 28 29 32 36 41 37 34 32 31 32 31 29 27 27 27 29 31 32 31 32 34 37 41 36 32 29 28 27 26 26 26 26
   40   27 27 27 27 26 26 27 29 32 39 40 32 29 27 27 27 26 26 26 26 26 27 27 27 29 32 40 39 32 29 27 26 26 27 27 27 27
   45   28 28 28 27 26 26 26 27 30 35 50 34 29 27 26 26 26 26 26 26 26 26 26 27 29 34 50 35 30 27 26 26 26 27 28 28 28
   50   27 27 26 26 25 25 25 25 27 30 35 35 31 30 29 30 32 34 35 34 32 30 29 30 31 35 35 30 27 25 25 25 25 26 26 27 27
   55   31 31 30 29 28 27 25 25 25 27 30 33 35 43 38 34 34 34 33 34 34 34 38 43 35 33 30 27 25 25 25 27 28 29 30 31 31
   60   31 31 32 32 33 33 32 31 30 30 32 33 35 34 29 29 33 27 25 27 33 29 29 34 35 33 32 30 30 31 32 33 33 32 32 31 31
   65   30 30 29 29 29 29 30 30 31 34 40 33 29 27 26 31 21 14 13 14 21 31 26 27 29 33 40 34 31 30 30 29 29 29 29 30 30
   70   34 34 33 32 32 33 33 30 26 25 26 26 25 25 27 22 12  7  6  7 12 22 27 25 25 26 26 25 26 30 33 33 32 32 33 34 34
   75   41 40 38 36 35 35 35 33 29 27 26 26 25 25 40 17  8  4  2  4  8 17 40 25 25 26 26 27 29 33 35 35 35 36 38 40 41
   80   43 41 37 33 30 27 25 25 25 28 36 29 26 32 23 12  6  2  1  2  6 12 23 32 26 29 36 29 25 25 25 27 30 33 37 41 43
   85   50 44 37 31 27 25 23 22 21 21 21 22 24 40 16  8  3  1  0  1  3  8 16 40 24 22 21 21 21 22 23 25 27 31 37 44 50
   90  119 49 37 30 25 23 22 21 20 19 18 19 22 32 14  7  2  0  0  0  2  7 14 32 22 19 18 19 20 21 22 23 25 30 37 49119
   95   50 44 37 31 27 25 23 22 21 21 21 22 24 40 16  8  3  1  0  1  3  8 16 40 24 22 21 21 21 22 23 25 27 31 37 44 50
  100   43 41 37 33 30 27 25 25 25 28 36 29 26 32 23 12  6  2  1  2  6 12 23 32 26 29 36 28 25 25 25 27 30 33 37 41 43
  105   41 40 38 36 35 35 35 33 29 27 26 26 25 25 40 17  8  4  2  4  8 17 40 25 25 26 26 27 29 33 35 35 35 36 38 40 41
  110   34 34 33 32 32 33 33 30 26 25 26 26 25 25 27 22 12  7  6  7 12 22 27 25 25 26 26 25 26 30 33 33 32 32 33 34 34
  115   30 30 29 29 29 29 30 30 31 34 40 33 29 27 26 31 21 14 13 14 21 31 26 27 29 33 40 34 31 30 30 29 29 29 29 30 30
  120   31 31 32 32 33 33 32 31 30 30 32 33 35 34 29 29 33 27 25 27 33 29 29 34 35 33 32 30 30 31 32 33 33 32 32 31 31
  125   31 31 30 29 28 27 25 25 25 27 30 33 35 43 38 34 34 34 33 34 34 34 38 43 35 33 30 27 25 25 25 27 28 29 30 31 31
  130   27 27 26 26 25 25 25 25 27 30 35 35 31 30 29 30 32 34 35 34 32 30 29 30 31 35 35 30 27 25 25 25 25 26 26 27 27
  135   28 28 28 27 26 26 26 27 30 35 50 34 29 27 26 26 26 26 26 26 26 26 26 27 29 34 50 35 30 27 26 26 26 27 28 28 28
  140   27 27 27 27 26 26 27 29 32 39 40 32 29 27 27 27 26 26 26 26 26 27 27 27 29 32 40 39 32 29 27 26 26 27 27 27 27
  145   26 26 26 26 27 28 29 32 36 41 37 34 32 31 32 31 29 27 27 27 29 31 32 31 32 34 37 41 36 32 29 28 27 26 26 26 26
  150   29 29 30 30 31 33 35 39 44 43 40 39 39 42 39 33 29 27 27 27 29 33 39 42 39 39 40 43 44 39 35 33 31 30 30 29 29
  155   38 38 39 40 42 45 51 55 50 47 47 52 52 41 35 32 29 28 28 28 29 32 35 41 52 52 47 47 50 55 51 45 42 40 39 38 38
  160   68 67 63 59 55 53 51 50 50 49 48 44 40 37 34 32 31 30 30 30 31 32 34 37 40 44 48 49 50 50 51 53 55 59 63 67 68
  165   52 52 52 52 51 51 50 49 47 45 43 41 39 38 36 35 35 34 34 34 35 35 36 38 39 41 43 45 47 49 50 51 51 52 52 52 52
  170   50 50 50 50 49 49 48 47 46 45 45 44 43 42 42 41 41 41 41 41 41 41 42 42 43 44 45 45 46 47 48 49 49 50 50 50 50
  175   55 55 55 55 55 55 54 54 54 54 54 54 53 53 53 53 53 53 53 53 53 53 53 53 53 54 54 54 54 54 54 55 55 55 55 55 55
  180  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125

                GAIN DEGRADATION IS
                  -0.284
```

Figure 4.17
Pattern 1. 2 Percent Error
Maximum Impact on Side Lobe 2

```
          BORESIGHT AT 90,30
THETA                                   PHI
         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0   126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126
    5    54 54 54 54 54 54 54 54 54 54 54 54 54 53 53 53 53 53 53 53 53 53 53 53 54 54 54 54 54 54 54 54 54 54 54 54 54
   10    41 41 41 41 41 41 42 42 42 42 42 42 42 42 42 42 42 41 41 41 42 42 42 42 42 42 42 42 42 42 42 41 41 41 41 41 41
   15    35 35 35 35 35 35 34 34 34 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 34 34 34 35 35 35 35 35 35
   20    33 33 33 33 32 32 32 31 31 30 30 30 30 31 31 31 31 31 31 31 31 31 31 31 30 30 30 30 31 31 32 32 32 33 33 33 33
   25    32 32 32 32 32 32 32 31 30 29 28 28 28 28 29 29 29 29 29 29 29 29 29 28 28 28 28 29 30 31 32 32 32 32 32 32 32
   30    28 28 28 29 29 30 31 32 32 31 30 28 28 28 29 30 31 30 30 30 31 30 29 28 28 28 30 31 32 32 31 30 29 29 28 28 28
   35    26 26 26 27 27 27 28 30 32 34 34 32 31 30 31 35 41 37 35 37 41 35 31 30 31 32 34 34 32 30 28 27 27 27 26 26 26
   40    31 31 30 30 29 29 29 30 32 36 42 43 36 33 33 34 35 33 31 33 35 34 33 33 36 43 42 36 32 30 29 29 29 30 30 31 31
   45    36 36 36 35 34 33 33 34 36 43 49 39 35 32 30 30 30 29 29 29 30 30 30 32 35 39 49 43 36 34 33 33 34 35 36 36 36
   50    32 32 31 31 30 29 29 30 31 33 34 33 33 31 30 29 30 32 33 32 30 29 30 31 33 33 34 33 31 30 29 29 30 31 31 32 32
   55    56 53 47 42 37 34 31 30 29 29 30 31 34 33 28 26 26 28 28 28 26 26 28 33 34 31 30 29 29 30 31 34 37 42 47 53 56
   60    30 30 30 30 31 34 40 51 37 33 31 32 41 33 25 25 29 32 28 32 29 25 25 33 41 32 31 33 37 51 40 34 31 30 30 30 30
   65    28 27 27 26 26 27 28 31 34 41 40 34 34 28 25 34 24 16 14 16 24 34 25 28 34 34 40 41 34 31 28 27 26 26 27 27 28
   70    31 31 30 29 28 28 30 31 30 30 31 31 28 25 28 25 13  8  6  8 13 25 28 25 28 31 31 30 30 31 30 28 28 29 30 31 31
   75    39 39 37 35 34 34 40 44 32 29 29 29 26 25 30 17  8  4  3  4  8 17 30 25 26 29 29 29 32 44 40 34 34 35 37 39 39
   80    57 55 51 47 43 39 34 30 28 27 31 34 28 25 19 12  6  2  1  2  6 12 19 25 28 34 31 27 28 30 34 39 43 47 51 55 57
   85    60 54 46 40 36 33 30 28 26 25 28 39 32 22 14  8  4  1  0  1  4  8 14 22 32 39 28 25 26 28 30 33 36 40 46 54 60
   90   127 56 44 37 33 30 28 27 26 25 26 32 35 21 12  6  3  0  0  0  3  6 12 21 35 32 26 25 26 27 28 30 33 37 44 56127
   95    60 54 46 40 36 33 30 28 26 25 28 39 32 22 14  8  4  1  0  1  4  8 14 22 32 39 28 25 26 28 30 33 36 40 46 54 60
  100    57 55 51 47 43 39 34 30 28 27 31 34 28 25 19 12  6  2  1  2  6 12 19 25 28 34 31 27 28 30 34 39 43 47 51 55 57
  105    39 39 37 35 34 34 40 44 32 29 29 29 26 25 30 17  8  4  3  4  8 17 30 25 26 29 29 29 32 44 40 34 34 35 37 39 39
  110    31 31 30 29 28 28 30 31 30 30 31 31 28 25 28 25 13  8  6  8 13 25 28 25 28 31 31 30 30 31 30 28 28 29 30 31 31
  115    28 27 27 26 26 27 28 31 34 41 40 34 34 28 25 34 24 16 14 16 24 34 25 28 34 34 40 41 34 31 28 27 26 26 27 27 28
  120    30 30 30 30 31 34 40 51 37 33 31 32 41 33 25 25 29 32 28 32 29 25 25 33 41 32 31 33 37 51 40 34 31 30 30 30 30
  125    56 53 47 42 37 34 31 30 29 29 30 31 34 33 28 26 26 28 28 28 26 26 28 33 34 31 30 29 29 30 31 34 37 42 47 53 56
  130    32 32 31 31 30 29 29 30 31 33 34 33 33 31 30 29 30 32 33 32 30 29 30 31 33 33 34 33 31 30 29 29 30 31 31 32 32
  135    36 36 36 35 34 33 33 34 36 43 49 39 35 32 30 30 30 29 29 29 30 30 30 32 35 39 49 43 36 34 33 33 34 35 36 36 36
  140    31 31 30 30 29 29 29 30 32 36 42 43 36 33 33 34 35 33 31 33 35 34 33 33 36 43 42 36 32 30 29 29 29 30 30 31 31
  145    26 26 26 27 27 27 28 30 32 34 34 32 31 30 31 35 41 37 35 37 41 35 31 30 31 32 34 34 32 30 28 27 27 27 26 26 26
  150    28 28 28 29 29 30 31 32 32 31 30 28 28 28 29 30 31 30 30 30 31 30 29 28 28 28 30 31 32 32 31 30 29 29 28 28 28
  155    32 32 32 32 32 32 32 31 30 29 28 28 28 28 29 29 29 29 29 29 29 29 29 28 28 28 28 29 30 31 32 32 32 32 32 32 32
  160    33 33 33 33 32 32 32 31 31 30 30 30 30 31 31 31 31 31 31 31 31 31 31 31 30 30 30 30 31 31 32 32 32 33 33 33 33
  165    35 35 35 35 35 35 34 34 34 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 35 34 34 34 35 35 35 35 35 35
  170    41 41 41 41 41 41 42 42 42 42 42 42 42 42 42 42 42 41 41 41 42 42 42 42 42 42 42 42 42 42 42 41 41 41 41 41 41
  175    54 54 54 54 54 54 54 54 54 54 54 54 54 53 53 53 53 53 53 53 53 53 53 53 54 54 54 54 54 54 54 54 54 54 54 54 54
  180   126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126

               GAIN DEGRADATION IS
                  -0.209
```

Figure 4.18
Pattern 1. 1 Percent Error
Maximum Impact on the Null

```
          BORESIGHT AT 90,90
THETA                                        PHI
          0   5  10  15  20  25  30  35  40  45  50  55  60  65  70  75  80  85  90  95  00  05  10  15  20  25  30  35  40  45  50  55  60  65  70  75  80

  0     126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126
  5      52  52  52  52  52  52  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  52  52  52  52  52  52
 10      37  37  37  37  38  38  38  38  39  39  39  40  40  41  41  41  41  41  41  41  41  41  41  41  40  40  39  39  39  38  38  38  38  37  37  37  37
 15      30  30  30  30  30  30  30  30  30  30  31  31  32  33  33  34  34  35  35  35  34  34  33  33  32  31  31  30  30  30  30  30  30  30  30  30  30
 20      28  27  27  27  27  26  26  26  25  25  25  26  26  27  28  29  30  31  31  31  30  29  28  27  26  26  25  25  25  26  26  26  27  27  27  27  28
 25      28  28  28  28  27  27  26  25  25  24  24  23  24  24  25  26  28  29  29  29  28  26  25  24  24  23  24  24  25  25  26  27  27  28  28  28  28
 30      27  27  27  27  27  27  27  26  25  25  24  23  22  23  24  25  28  30  30  30  28  25  24  23  22  23  24  25  25  26  27  27  27  27  27  27  27
 35      26  26  26  26  27  27  27  28  28  27  25  25  23  23  24  26  31  38  37  38  31  26  24  23  23  25  25  27  28  28  27  27  27  26  26  26  26
 40      31  30  30  29  29  28  28  29  30  31  30  28  26  25  25  28  34  38  35  38  34  28  25  25  26  28  30  31  30  29  28  28  29  29  30  30  31
 45      39  39  38  37  35  33  32  32  33  35  36  34  30  28  27  28  30  32  31  32  30  28  27  28  30  34  36  35  33  32  32  33  35  37  38  39  39
 50      32  32  32  31  31  30  30  30  31  33  33  32  30  28  26  26  28  32  34  32  28  26  26  28  30  32  33  33  31  30  30  30  31  31  32  32  32
 55      56  52  46  41  36  33  30  29  28  29  30  32  32  28  25  25  25  27  28  27  25  25  25  28  32  32  30  29  28  29  30  33  36  41  46  52  56
 60      29  29  29  30  31  35  48  39  33  31  31  35  41  27  24  24  28  33  28  33  28  24  24  27  41  35  31  31  33  39  48  35  31  30  29  29  29
 65      27  26  26  26  26  26  28  32  38  45  50  38  32  26  24  28  24  16  14  16  24  28  24  26  32  38  50  45  38  32  28  26  26  26  26  26  27
 70      31  30  29  28  28  28  29  31  30  29  30  29  26  25  26  26  13   8   6   8  13  26  26  25  26  29  30  29  30  31  29  28  28  28  29  30  31
 75      40  39  37  35  34  35  43  39  30  27  27  27  25  25  27  17   8   4   3   4   8  17  27  25  25  27  27  27  30  39  43  35  34  35  37  39  40
 80      55  53  49  45  41  36  32  29  26  26  28  30  27  24  19  12   6   2   1   2   6  12  19  24  27  30  28  26  26  29  32  36  41  45  49  53  55
 85      59  53  45  39  35  31  29  26  25  24  25  33  29  21  13   8   4   1   0   1   4   8  13  21  29  33  25  24  25  26  29  31  35  39  45  53  59
 90     126  55  43  37  32  29  27  26  25  23  24  29  29  19  12   6   3   1   0   1   3   6  12  19  29  29  24  23  25  26  27  29  32  37  43  55126
 95      59  53  45  39  35  31  29  26  25  24  25  33  29  21  13   8   4   1   0   1   4   8  13  21  29  33  25  24  25  26  29  31  35  39  45  53  59
100      55  53  49  45  41  36  32  29  26  26  28  30  27  24  19  12   6   2   1   2   6  12  19  24  27  30  28  26  26  29  32  36  41  45  49  53  55
105      40  39  37  35  34  35  43  39  30  27  27  27  25  25  27  17   8   4   3   4   8  17  27  25  25  27  27  27  30  39  43  35  34  35  37  39  40
110      31  30  29  28  28  28  29  31  30  29  30  29  26  25  26  26  13   8   6   8  13  26  26  25  26  29  30  29  30  31  29  28  28  28  29  30  31
115      27  26  26  26  26  26  28  32  38  45  50  38  32  26  24  28  24  16  14  16  24  28  24  26  32  38  50  45  38  32  28  26  26  26  26  26  27
120      29  29  29  30  31  35  48  39  33  31  31  35  41  27  24  24  28  33  28  33  28  24  24  27  41  35  31  31  33  39  48  35  31  30  29  29  29
125      56  52  46  41  36  33  30  29  28  29  30  32  32  28  25  25  25  27  28  27  25  25  25  28  32  32  30  29  28  29  30  33  36  41  46  52  56
130      32  32  32  31  31  30  30  30  31  33  33  32  30  28  26  26  28  32  34  32  28  26  26  28  30  32  33  33  31  30  30  30  31  31  32  32  32
135      39  39  38  37  35  33  32  32  33  35  36  34  30  28  27  28  30  32  31  32  30  28  27  28  30  34  36  35  33  32  32  33  35  37  38  39  39
140      31  30  30  29  29  28  28  29  30  31  30  28  26  25  25  28  34  38  35  38  34  28  25  25  26  28  30  31  30  29  28  28  29  29  30  30  31
145      26  26  26  26  27  27  27  28  28  27  25  25  23  23  24  26  31  38  37  38  31  26  24  23  23  25  25  27  28  28  27  27  27  26  26  26  26
150      27  27  27  27  27  27  27  26  25  25  24  23  22  23  24  25  28  30  30  30  28  25  24  23  22  23  24  25  25  26  27  27  27  27  27  27  27
155      28  28  28  28  27  27  26  25  25  24  24  23  24  24  25  26  28  29  29  29  28  26  25  24  24  23  24  24  25  25  26  27  27  28  28  28  28
160      28  27  27  27  27  26  26  26  25  25  25  26  26  27  28  29  30  31  31  31  30  29  28  27  26  26  25  25  25  26  26  26  27  27  27  27  28
165      30  30  30  30  30  30  30  30  30  30  31  31  32  33  33  34  34  35  35  35  34  34  33  33  32  31  31  30  30  30  30  30  30  30  30  30  30
170      37  37  37  37  38  38  38  38  39  39  39  40  40  41  41  41  41  41  41  41  41  41  41  41  40  40  39  39  39  38  38  38  38  37  37  37  37
175      52  52  52  52  52  52  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  53  52  52  52  52  52  52
180     126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126 126

                 GAIN DEGRADATION IS
                   -8.213
```

Figure 4.19
Pattern 1. 2 Percent Error
Maximum Impact on the Null

```
           BORESIGHT AT 90,90

THETA                                PHI

         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0   128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128
   5    58 58 58 58 58 58 57 57 57 57 57 57 57 56 56 56 56 56 56 56 56 56 56 56 57 57 57 57 57 57 57 58 58 58 58 58 58
  10    49 49 49 49 49 49 48 48 48 47 47 46 46 45 45 45 44 44 44 44 44 45 45 45 46 46 47 47 48 48 48 49 49 49 49 49 49
  15    41 41 41 41 42 42 42 42 42 42 42 42 41 40 39 39 38 38 38 38 38 39 39 40 41 42 42 42 42 42 42 42 42 41 41 41 41
  20    35 35 35 35 35 36 36 36 37 37 38 38 38 38 37 36 34 34 34 34 34 36 37 38 38 38 38 37 37 36 36 36 35 35 35 35 35
  25    32 32 32 32 32 32 32 32 32 33 34 35 36 37 37 35 34 32 32 32 34 35 37 37 36 35 34 33 32 32 32 32 32 32 32 32 32
  30    37 36 35 34 33 32 31 30 30 30 31 32 33 36 39 40 37 34 33 34 37 40 39 36 33 32 31 30 30 30 31 32 33 34 35 36 37
  35    35 36 37 40 47 44 37 33 30 29 29 30 31 34 37 43 48 40 38 40 48 43 37 34 31 30 29 29 30 33 37 44 47 40 37 36 35
  40    27 27 28 28 29 32 36 51 39 32 30 29 30 32 34 34 34 34 33 34 34 34 34 32 30 29 30 32 39 51 36 32 29 28 28 27 27
  45    28 28 28 28 28 28 29 32 38 41 33 31 30 32 35 34 33 32 31 32 33 34 35 32 30 31 33 41 38 32 29 28 28 28 28 28 28
  50    28 28 28 28 28 29 30 32 35 39 36 32 31 33 39 48 38 34 34 34 38 48 39 33 31 32 36 39 35 32 30 29 28 28 28 28 28
  55    29 29 29 29 29 29 29 31 36 54 38 34 33 34 32 30 29 31 32 31 29 30 32 34 33 34 38 54 36 31 29 29 29 29 29 29 29
  60    36 36 35 35 34 34 33 32 33 35 37 37 38 33 28 29 37 35 29 35 37 29 28 33 38 37 37 35 33 32 33 34 34 35 35 36 36
  65    39 39 39 39 40 42 52 47 40 37 37 37 33 30 30 30 21 16 14 16 21 30 30 30 33 37 37 37 40 47 52 42 40 39 39 39 39
  70    47 47 46 45 43 42 40 37 36 37 45 38 31 31 26 17 11  8  7  8 11 17 26 31 31 38 45 37 36 37 40 42 43 45 46 47 47
  75    39 38 36 34 33 33 35 37 32 30 36 38 33 30 17 10  7  5  4  5  7 10 17 30 33 38 36 30 32 37 35 33 33 34 36 38 39
  80    44 42 38 35 32 32 35 41 32 30 43 30 29 20 11  7  5  3  3  3  5  7 11 20 29 30 43 30 32 41 35 32 32 35 38 42 44
  85    60 54 46 41 38 39 50 36 30 32 33 24 24 15  8  5  3  2  1  2  3  5  8 15 24 24 33 32 30 36 50 39 38 41 46 54 60
  90   143 65 53 47 45 50 42 32 29 32 29 23 22 14  7  4  3  1  0  1  3  4  7 14 22 23 29 32 29 32 42 50 45 47 53 65143
  95    60 54 46 41 38 39 50 36 30 32 33 24 24 15  8  5  3  2  1  2  3  5  8 15 24 24 33 32 30 36 50 39 38 41 46 54 60
 100    44 42 38 35 32 32 35 41 32 30 43 30 29 20 11  7  5  3  3  3  5  7 11 20 29 30 43 30 32 41 35 32 32 35 38 42 44
 105    39 38 36 34 33 33 35 37 32 30 36 38 33 30 17 10  7  5  4  5  7 10 17 30 33 38 36 30 32 37 35 33 33 34 36 38 39
 110    47 47 46 45 43 42 40 37 36 37 45 38 31 31 26 17 11  8  7  8 11 17 26 31 31 38 45 37 36 37 40 42 43 45 46 47 47
 115    39 39 39 39 40 42 52 47 40 37 37 37 33 30 30 30 21 16 14 16 21 30 30 30 33 37 37 37 40 47 52 42 40 39 39 39 39
 120    36 36 35 35 34 34 33 32 33 35 37 37 38 33 28 29 37 35 29 35 37 29 28 33 38 37 37 35 33 32 33 34 34 35 35 36 36
 125    29 29 29 29 29 29 29 31 36 54 38 34 33 34 32 30 29 31 32 31 29 30 32 34 33 34 38 54 36 31 29 29 29 29 29 29 29
 130    28 28 28 28 28 29 30 32 35 39 36 32 31 33 39 48 38 34 34 34 38 48 39 33 31 32 36 39 35 32 30 29 28 28 28 28 28
 135    28 28 28 28 28 28 29 32 38 41 33 31 30 32 35 34 33 32 31 32 33 34 35 32 30 31 33 41 38 32 29 28 28 28 28 28 28
 140    27 27 28 28 29 32 36 51 39 32 30 29 30 32 34 34 34 34 33 34 34 34 34 32 30 29 30 32 39 51 36 32 29 28 28 27 27
 145    35 36 37 40 47 44 37 33 30 29 29 30 31 34 37 43 48 40 38 40 48 43 37 34 31 30 29 29 30 33 37 44 47 40 37 36 35
 150    37 36 35 34 33 32 31 30 30 30 31 32 33 36 39 40 37 34 33 34 37 40 39 36 33 32 31 30 30 30 31 32 33 34 35 36 37
 155    32 32 32 32 32 32 32 32 32 33 34 35 36 37 37 35 34 32 32 32 34 35 37 37 36 35 34 33 32 32 32 32 32 32 32 32 32
 160    35 35 35 35 35 36 36 36 37 37 38 38 38 38 37 36 34 34 34 34 34 36 37 38 38 38 38 37 37 36 36 36 35 35 35 35 35
 165    41 41 41 41 42 42 42 42 42 42 42 42 41 40 39 39 38 38 38 38 38 39 39 40 41 42 42 42 42 42 42 42 42 41 41 41 41
 170    49 49 49 49 49 49 48 48 48 47 47 46 46 45 45 45 44 44 44 44 44 45 45 45 46 46 47 47 48 48 48 49 49 49 49 49 49
 175    58 58 58 58 58 58 57 57 57 57 57 57 57 56 56 56 56 56 56 56 56 56 56 56 57 57 57 57 57 57 57 58 58 58 58 58 58
 180   128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128

                GAIN DEGRADATION IS
                  -9.131
```

Figure 4.20
Pattern 2. 1 Percent Error
Maximum Impact on the Main Beam

```
          BORESIGHT AT 90,90
THETA                                    PHI
         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0  128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128
    5   59 59 59 59 59 58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58 59 59 59 59 59
   10   49 49 49 49 49 49 49 49 48 48 48 47 47 46 46 46 45 45 45 45 45 46 46 46 47 47 48 48 48 49 49 49 49 49 49 49 49
   15   41 41 41 41 41 41 41 41 42 42 42 42 42 41 40 40 39 39 39 39 39 40 40 41 42 42 42 42 42 41 41 41 41 41 41 41 41
   20   36 36 36 36 36 36 36 36 36 36 37 38 38 38 38 37 36 35 35 35 36 37 38 38 38 38 37 36 36 36 36 36 36 36 36 36 36
   25   34 34 34 34 33 33 33 33 32 33 33 34 35 36 37 36 35 33 33 33 35 36 37 36 35 34 33 33 32 33 33 33 33 34 34 34 34
   30   40 39 38 37 35 34 32 31 31 30 31 31 32 34 37 41 39 36 35 36 39 41 37 34 32 31 31 30 31 31 32 34 35 37 38 39 40
   35   34 34 35 37 41 45 39 34 32 30 29 30 31 32 35 40 47 41 39 41 47 40 35 32 31 30 29 30 32 34 39 45 41 37 35 34 34
   40   27 27 27 28 29 31 35 46 39 33 30 29 30 32 33 33 34 34 33 34 34 33 33 32 30 29 30 33 39 46 35 31 29 28 27 27 27
   45   27 27 27 27 27 27 29 32 39 42 33 30 30 32 35 34 33 32 32 32 33 34 35 32 30 30 33 42 39 32 29 27 27 27 27 27 27
   50   27 27 27 27 27 28 29 31 35 40 35 32 31 33 40 43 36 34 33 34 36 43 40 33 31 32 35 40 35 31 29 28 27 27 27 27 27
   55   28 28 28 27 27 27 28 30 36 56 36 32 33 34 31 28 29 30 32 30 29 28 31 34 33 32 36 56 36 30 28 27 27 27 28 28 28
   60   34 34 33 33 32 31 31 31 32 37 39 35 39 35 28 27 34 35 29 35 34 27 28 35 39 35 39 37 32 31 31 31 32 33 33 34 34
   65   43 43 43 43 44 46 43 39 37 37 39 45 39 31 29 29 21 16 14 16 21 29 29 31 39 45 39 37 37 39 43 46 44 43 43 43 43
   70   43 43 42 40 39 39 39 37 35 36 43 39 31 30 25 17 12  9  8  9 12 17 25 30 31 39 43 36 35 37 39 39 39 40 42 43 43
   75   38 37 35 33 32 32 33 35 31 30 36 35 31 31 17 11  7  5  5  5  7 11 17 31 31 35 36 30 31 35 33 32 32 33 35 37 38
   80   45 43 39 35 33 32 35 38 31 31 40 30 31 20 11  7  5  3  3  3  5  7 11 20 31 30 40 31 31 38 35 32 33 35 39 43 45
   85   63 57 49 44 41 42 44 35 30 32 32 25 24 15  8  5  4  2  1  2  4  5  8 15 24 25 32 32 30 35 44 42 41 44 49 57 63
   90  147 71 59 54 52 48 38 32 29 33 29 24 23 13  7  5  3  1  0  1  3  5  7 13 23 24 29 33 29 32 38 48 52 54 59 71147
   95   63 57 49 44 41 42 44 35 30 32 32 25 24 15  8  5  4  2  1  2  4  5  8 15 24 25 32 32 30 35 44 42 41 44 49 57 63
  100   45 43 39 35 33 32 35 38 31 31 40 30 31 20 11  7  5  3  3  3  5  7 11 20 31 30 40 31 31 38 35 32 33 35 39 43 45
  105   38 37 35 33 32 32 33 35 31 30 36 35 31 31 17 11  7  5  5  5  7 11 17 31 31 35 36 30 31 35 33 32 32 33 35 37 38
  110   43 43 42 40 39 39 39 37 35 36 43 39 31 30 25 17 12  9  8  9 12 17 25 30 31 39 43 36 35 37 39 39 39 40 42 43 43
  115   43 43 43 43 44 46 43 39 37 37 39 45 39 31 29 29 21 16 14 16 21 29 29 31 39 45 39 37 37 39 43 46 44 43 43 43 43
  120   34 34 33 33 32 31 31 31 32 37 39 35 39 35 28 27 34 35 29 35 34 27 28 35 39 35 39 37 32 31 31 31 32 33 33 34 34
  125   28 28 28 27 27 27 28 30 36 56 36 32 33 34 31 28 29 30 32 30 29 28 31 34 33 32 36 56 36 30 28 27 27 27 28 28 28
  130   27 27 27 27 27 28 29 31 35 40 35 32 31 33 40 43 36 34 33 34 36 43 40 33 31 32 35 40 35 31 29 28 27 27 27 27 27
  135   27 27 27 27 27 27 29 32 39 42 33 30 30 32 35 34 33 32 32 32 33 34 35 32 30 30 33 42 39 32 29 27 27 27 27 27 27
  140   27 27 27 28 29 31 35 46 39 33 30 29 30 32 33 33 34 34 33 34 34 33 33 32 30 29 30 33 39 46 35 31 29 28 27 27 27
  145   34 34 35 37 41 45 39 34 32 30 29 30 31 32 35 40 47 41 39 41 47 40 35 32 31 30 29 30 32 34 39 45 41 37 35 34 34
  150   40 39 38 37 35 34 32 31 31 30 31 31 32 34 37 41 39 36 35 36 39 41 37 34 32 31 31 30 31 31 32 34 35 37 38 39 40
  155   34 34 34 34 33 33 33 33 32 33 33 34 35 36 37 36 35 33 33 33 35 36 37 36 35 34 33 33 32 33 33 33 33 34 34 34 34
  160   36 36 36 36 36 36 36 36 36 36 37 38 38 38 38 37 36 35 35 35 36 37 38 38 38 38 37 36 36 36 36 36 36 36 36 36 36
  165   41 41 41 41 41 41 41 41 42 42 42 42 42 41 40 40 39 39 39 39 39 40 40 41 42 42 42 42 42 41 41 41 41 41 41 41 41
  170   49 49 49 49 49 49 49 49 48 48 48 47 47 46 46 46 45 45 45 45 45 46 46 46 47 47 48 48 48 49 49 49 49 49 49 49 49
  175   59 59 59 59 59 58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58 59 59 59 59 59
  180  128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128

          GAIN DEGRADATION IS
            -9.037
```

Figure 4.21
Pattern 2. 2 Percent Error
Maximum Impact on the Main Beam

```
          BORESIGHT AT 90,90
THETA                                    PHI
         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0   116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116
  5    47 47 47 47 47 47 46 46 46 46 46 46 45 45 45 45 45 45 45 45 45 45 45 45 45 46 46 46 46 46 46 47 47 47 47 47 47
 10    42 42 41 41 41 40 39 39 38 37 36 36 35 34 34 33 33 33 33 33 33 33 34 34 35 36 36 37 38 39 39 40 41 41 41 42 42
 15    45 45 45 44 44 43 42 40 38 36 34 32 31 29 28 27 27 26 26 26 27 27 28 29 31 32 34 36 38 40 42 43 44 44 45 45 45
 20    39 39 39 39 40 40 41 41 41 40 37 34 31 28 26 24 23 23 23 23 23 24 26 28 31 34 37 40 41 41 41 40 40 39 39 39 39
 25    32 32 32 32 33 33 34 35 37 38 39 38 34 29 25 23 22 21 20 21 22 23 25 29 34 38 39 38 37 35 34 33 33 32 32 32 32
 30    34 34 33 32 31 31 30 31 31 33 35 37 39 35 28 24 22 20 19 20 22 24 28 35 39 37 35 33 31 31 30 31 31 32 33 34 34
 35    36 37 38 43 48 40 34 31 30 30 31 34 38 45 36 28 23 21 21 21 23 28 36 45 38 34 31 30 30 31 34 40 48 43 38 37 36
 40    28 28 28 29 30 33 39 54 36 32 31 32 36 43 44 34 28 24 23 24 28 34 44 43 36 32 31 32 36 54 39 33 30 29 28 28 28
 45    29 29 29 29 29 30 31 34 40 38 34 32 34 43 42 33 29 26 26 26 29 33 42 43 34 32 34 38 40 34 31 30 29 29 29 29 29
 50    28 28 28 28 29 30 32 36 41 40 35 34 35 39 36 30 28 26 26 26 28 30 36 39 35 34 35 40 41 36 32 30 29 28 28 28 28
 55    29 29 29 28 28 29 29 31 35 41 38 35 36 34 29 26 24 24 25 24 24 26 29 34 36 35 38 41 35 31 29 29 28 28 29 29 29
 60    32 32 32 32 32 33 33 32 32 33 34 36 35 30 26 25 28 35 41 35 28 25 26 30 35 36 34 33 32 32 33 33 32 32 32 32 32
 65    35 35 34 34 34 35 38 43 45 39 36 33 30 28 28 28 21 16 15 16 21 28 28 28 30 33 36 39 45 43 38 35 34 34 34 35 35
 70    42 42 40 39 38 36 35 34 34 36 44 35 29 30 25 16 10  7  6  7 10 16 25 30 29 35 44 36 34 34 35 36 38 39 40 42 42
 75    37 36 34 32 31 30 32 34 31 29 34 38 33 30 16  9  6  4  3  4  6  9 16 30 33 38 34 29 31 34 32 30 31 32 34 36 37
 80    41 39 36 32 29 29 31 37 31 29 43 28 26 19 10  5  3  2  2  2  3  5 10 19 26 28 43 29 31 37 31 29 29 32 36 39 41
 85    55 49 41 35 32 32 36 39 29 30 34 23 21 14  7  3  2  1  1  1  2  3  7 14 21 23 34 30 29 39 36 32 32 35 41 49 55
 90   130 56 44 38 34 34 43 34 27 29 30 21 19 13  6  3  2  1  0  1  2  3  6 13 19 21 30 29 27 34 43 34 34 38 44 56130
 95    55 49 41 35 32 32 36 39 29 30 34 23 21 14  7  3  2  1  1  1  2  3  7 14 21 23 34 30 29 39 36 32 32 35 41 49 55
100    41 39 36 32 29 29 31 37 31 29 43 28 26 19 10  5  3  2  2  2  3  5 10 19 26 28 43 29 31 37 31 29 29 32 36 39 41
105    37 36 34 32 31 30 32 34 31 29 34 38 33 30 16  9  6  4  3  4  6  9 16 30 33 38 34 29 31 34 32 30 31 32 34 36 37
110    42 42 40 39 38 36 35 34 34 36 44 35 29 30 25 16 10  7  6  7 10 16 25 30 29 35 44 36 34 34 35 36 38 39 40 42 42
115    35 35 34 34 34 35 38 43 45 39 36 33 30 28 28 28 21 16 15 16 21 28 28 28 30 33 36 39 45 43 38 35 34 34 34 35 35
120    32 32 32 32 32 33 33 32 32 33 34 36 35 30 26 25 28 35 41 35 28 25 26 30 35 36 34 33 32 32 33 33 32 32 32 32 32
125    29 29 29 28 28 29 29 31 35 41 38 35 36 34 29 26 24 24 25 24 24 26 29 34 36 35 38 41 35 31 29 29 28 28 29 29 29
130    28 28 28 28 29 30 32 36 41 40 35 34 35 39 36 30 28 26 26 26 28 30 36 39 35 34 35 40 41 36 32 30 29 28 28 28 28
135    29 29 29 29 29 30 31 34 40 38 34 32 34 43 42 33 29 26 26 26 29 33 42 43 34 32 34 38 40 34 31 30 29 29 29 29 29
140    28 28 28 29 30 33 39 54 36 32 31 32 36 43 44 34 28 24 23 24 28 34 44 43 36 32 31 32 36 54 39 33 30 29 28 28 28
145    36 37 38 43 48 40 34 31 30 30 31 34 38 45 36 28 23 21 21 21 23 28 36 45 38 34 31 30 30 31 34 40 48 43 38 37 36
150    34 34 33 32 31 31 30 31 31 33 35 37 39 35 28 24 22 20 19 20 22 24 28 35 39 37 35 33 31 31 30 31 31 32 33 34 34
155    32 32 32 32 33 33 34 35 37 38 39 38 34 29 25 23 22 21 20 21 22 23 25 29 34 38 39 38 37 35 34 33 33 32 32 32 32
160    39 39 39 39 40 40 41 41 41 40 37 34 31 28 26 24 23 23 23 23 23 24 26 28 31 34 37 40 41 41 41 40 40 39 39 39 39
165    45 45 45 44 44 43 42 40 38 36 34 32 31 29 28 27 27 26 26 26 27 27 28 29 31 32 34 36 38 40 42 43 44 44 45 45 45
170    42 42 41 41 41 40 39 39 38 37 36 36 35 34 34 33 33 33 33 33 33 33 34 34 35 36 36 37 38 39 39 40 41 41 41 42 42
175    47 47 47 47 47 47 46 46 46 46 46 46 45 45 45 45 45 45 45 45 45 45 45 45 45 46 46 46 46 46 46 47 47 47 47 47 47
180   116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116116

                  GAIN DEGRADATION IS
                     -9.147
```

Figure 4.22
Pattern 2. 1 Percent Error
Maximum Impact on Side Lobe 1

```
          BORESIGHT AT 30,30

THETA                                PHI

         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0   112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112
  5    43 43 43 43 43 43 43 43 43 42 42 42 42 42 42 41 41 41 41 41 41 41 42 42 42 42 42 42 43 43 43 43 43 43 43 43 43
 10    39 39 39 38 38 37 36 35 35 34 33 32 31 31 30 30 30 29 29 29 30 30 30 31 31 32 33 34 35 35 36 37 38 38 39 39 39
 15    54 53 52 50 47 44 41 39 36 34 31 29 28 26 25 24 23 23 23 23 23 24 25 26 28 29 31 34 36 39 41 44 47 50 52 53 54
 20    46 46 47 48 49 50 52 56 52 43 36 31 28 25 23 21 20 19 19 19 20 21 23 25 28 31 36 43 52 56 52 50 49 48 47 46 46
 25    32 32 33 33 34 36 38 42 46 49 61 41 32 26 23 20 18 17 16 17 18 20 23 26 32 41 61 49 46 42 38 36 34 33 33 32 32
 30    32 32 31 31 30 30 30 31 34 39 46 50 45 31 24 20 17 16 15 16 17 20 24 31 45 50 46 39 34 31 30 30 30 31 31 32 32
 35    38 39 42 50 43 36 32 30 30 31 35 45 46 39 29 23 19 17 16 17 19 23 29 39 46 45 35 31 30 30 32 36 43 50 42 39 38
 40    28 28 28 29 30 34 41 46 35 32 32 36 59 38 32 26 22 19 18 19 22 26 32 38 59 36 32 32 35 46 41 34 30 29 28 28 28
 45    29 29 29 29 29 30 32 35 42 39 35 35 41 39 31 26 23 21 21 21 23 26 31 39 41 35 35 39 42 35 32 30 29 29 29 29 29
 50    27 28 28 28 29 30 32 36 42 41 37 36 40 35 29 25 23 22 21 22 23 25 29 35 40 36 37 41 42 36 32 30 29 28 28 28 27
 55    28 28 28 27 28 28 29 32 36 40 38 37 40 32 26 23 22 22 21 22 22 23 26 32 40 37 38 40 36 32 29 28 28 27 28 28 28
 60    30 30 30 30 30 30 31 32 33 33 34 35 34 28 25 23 24 26 27 26 24 23 25 28 34 35 34 33 33 32 31 30 30 30 30 30 30
 65    35 35 34 34 33 34 35 39 45 41 36 32 28 26 26 26 22 17 16 17 22 26 26 26 28 32 36 41 45 39 35 34 33 34 34 35 35
 70    39 39 38 36 35 34 34 33 33 34 38 33 28 28 24 16 11  8  7  8 11 16 24 28 28 33 38 34 33 33 34 34 35 36 38 39 39
 75    35 34 32 30 29 28 29 31 31 29 33 37 33 29 16  9  6  4  3  4  6  9 16 29 33 37 33 29 31 31 29 28 29 30 32 34 35
 80    40 38 34 31 28 27 28 33 32 30 42 29 26 19 10  5  3  2  2  2  3  5 10 19 26 29 42 30 32 33 28 27 28 31 34 38 40
 85    54 48 40 34 31 30 33 39 30 30 34 22 21 14  7  3  2  2  1  2  2  3  7 14 21 22 34 30 30 39 33 30 31 34 40 48 54
 90   128 55 43 37 33 32 38 36 28 29 29 20 19 13  6  3  2  1  0  1  2  3  6 13 19 20 29 29 28 36 38 32 33 37 43 55128
 95    54 48 40 34 31 30 33 39 30 30 34 22 21 14  7  3  2  2  1  2  2  3  7 14 21 22 34 30 30 39 33 30 31 34 40 48 54
100    40 38 34 31 28 27 28 33 32 30 42 29 26 19 10  5  3  2  2  2  3  5 10 19 26 29 42 30 32 33 28 27 28 31 34 38 40
105    35 34 32 30 29 28 29 31 31 29 33 37 33 29 16  9  6  4  3  4  6  9 16 29 33 37 33 29 31 31 29 28 29 30 32 34 35
110    39 39 38 36 35 34 34 33 33 34 38 33 28 28 24 16 11  8  7  8 11 16 24 28 28 33 38 34 33 33 34 34 35 36 38 39 39
115    35 35 34 34 33 34 35 39 45 41 36 32 28 26 26 26 22 17 16 17 22 26 26 26 28 32 36 41 45 39 35 34 33 34 34 35 35
120    30 30 30 30 30 30 31 32 33 33 34 35 34 28 25 23 24 26 27 26 24 23 25 28 34 35 34 33 33 32 31 30 30 30 30 30 30
125    28 28 28 27 28 28 29 32 36 40 38 37 40 32 26 23 22 22 21 22 22 23 26 32 40 37 38 40 36 32 29 28 28 27 28 28 28
130    27 28 28 28 29 30 32 36 42 41 37 36 40 35 29 25 23 22 21 22 23 25 29 35 40 36 37 41 42 36 32 30 29 28 28 28 27
135    29 29 29 29 29 30 32 35 42 39 35 35 41 39 31 26 23 21 21 21 23 26 31 39 41 35 35 39 42 35 32 30 29 29 29 29 29
140    28 28 28 29 30 34 41 46 35 32 32 36 59 38 32 26 22 19 18 19 22 26 32 38 59 36 32 32 35 46 41 34 30 29 28 28 28
145    38 39 42 50 43 36 32 30 30 31 35 45 46 39 29 23 19 17 16 17 19 23 29 39 46 45 35 31 30 30 32 36 43 50 42 39 38
150    32 32 31 31 30 30 30 31 34 39 46 50 45 31 24 20 17 16 15 16 17 20 24 31 45 50 46 39 34 31 30 30 30 31 31 32 32
155    32 32 33 33 34 36 38 42 46 49 61 41 32 26 23 20 18 17 16 17 18 20 23 26 32 41 61 49 46 42 38 36 34 33 33 32 32
160    46 46 47 48 49 50 52 56 52 43 36 31 28 25 23 21 20 19 19 19 20 21 23 25 28 31 36 43 52 56 52 50 49 48 47 46 46
165    54 53 52 50 47 44 41 39 36 34 31 29 28 26 25 24 23 23 23 23 23 24 25 26 28 29 31 34 36 39 41 44 47 50 52 53 54
170    39 39 39 38 38 37 36 35 35 34 33 32 31 31 30 30 30 29 29 29 30 30 30 31 31 32 33 34 35 35 36 37 38 38 39 39 39
175    43 43 43 43 43 43 43 43 43 42 42 42 42 42 42 41 41 41 41 41 41 41 42 42 42 42 42 42 43 43 43 43 43 43 43 43 43
180   112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112112

                 GAIN DEGRADATION IS
                   -9.077
```

Figure 4.23
Pattern 2. 2 Percent Error
Maximum Impact on Side Lobe 1

```
          BORESIGHT AT 90,30

THETA                              PHI

        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0 123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123
    5  53 53 53 53 53 53 53 53 52 52 52 52 52 52 52 51 51 51 51 51 51 51 52 52 52 52 52 52 52 53 53 53 53 53 53 53 53
   10  46 46 45 45 45 45 44 44 43 43 42 42 41 41 40 40 40 39 39 39 40 40 40 41 41 42 42 43 43 44 44 45 45 45 45 46 46
   15  40 40 40 41 41 41 41 41 40 39 39 38 37 35 35 34 33 33 33 33 33 34 35 35 37 38 39 39 40 41 41 41 41 41 40 40 40
   20  33 33 33 33 34 34 35 35 36 37 37 36 35 33 32 31 29 29 29 29 29 31 32 33 35 36 37 37 36 35 35 34 34 33 33 33 33
   25  29 29 29 29 29 29 29 30 31 32 33 34 35 34 32 30 28 27 27 27 28 30 32 34 35 34 33 32 31 30 29 29 29 29 29 29 29
   30  33 33 32 31 30 28 28 27 27 28 29 31 34 37 36 32 30 28 27 28 30 32 36 37 34 31 29 28 27 27 28 28 30 31 32 33 33
   35  29 29 30 31 33 35 33 30 27 26 26 28 31 39 50 37 33 31 30 31 33 37 50 39 31 28 26 26 27 30 33 35 33 31 30 29 29
   40  23 23 23 23 24 25 28 32 34 30 27 27 29 36 41 32 29 28 27 28 29 32 41 36 29 27 27 30 34 32 28 25 24 23 23 23 23
   45  23 23 23 23 23 23 23 25 29 37 33 29 29 33 49 31 27 26 25 26 27 31 49 33 29 29 33 37 29 25 23 23 23 23 23 23 23
   50  22 22 22 22 22 23 23 23 26 30 44 34 30 31 35 35 31 29 29 29 31 35 35 31 30 34 44 30 26 23 23 23 22 22 22 22 22
   55  23 23 23 23 23 23 23 23 25 29 37 39 33 30 27 27 28 32 34 32 28 27 27 30 33 39 37 29 25 23 23 23 23 23 23 23 23
   60  30 30 30 29 28 27 26 26 26 27 31 34 33 29 25 26 34 34 29 34 34 26 25 29 33 34 31 27 26 26 26 27 28 29 30 30 30
   65  35 35 35 35 36 37 38 35 32 30 30 30 29 27 28 29 20 15 13 15 20 29 28 27 29 30 30 30 32 35 38 37 36 35 35 35 35
   70  44 44 43 42 41 41 42 44 45 50 41 32 28 29 24 15 10  7  6  7 10 15 24 29 28 32 41 50 45 44 42 41 41 42 43 44 44
   75  35 34 32 30 28 28 30 39 37 30 33 34 32 29 15  9  5  3  3  3  5  9 15 29 32 34 33 30 37 39 30 28 28 30 32 34 35
   80  39 37 34 30 27 26 28 36 33 28 33 30 28 19 10  5  3  2  2  2  3  5 10 19 28 30 33 28 33 36 28 26 27 30 34 37 39
   85  54 48 40 34 31 30 32 33 27 27 31 23 22 14  7  3  2  1  1  1  2  3  7 14 22 23 31 27 27 33 32 30 31 34 40 48 54
   90 128 56 44 38 34 32 33 29 26 26 28 21 20 13  6  3  2  1  0  1  2  3  6 13 20 21 28 26 26 29 33 32 34 38 44 56128
   95  54 48 40 34 31 30 32 33 27 27 31 23 22 14  7  3  2  1  1  1  2  3  7 14 22 23 31 27 27 33 32 30 31 34 40 48 54
  100  39 37 34 30 27 26 28 36 33 28 33 30 28 19 10  5  3  2  2  2  3  5 10 19 28 30 33 28 33 36 28 26 27 30 34 37 39
  105  35 34 32 30 28 28 30 39 37 30 33 34 32 29 15  9  5  3  3  3  5  9 15 29 32 34 33 30 37 39 30 28 28 30 32 34 35
  110  44 44 43 42 41 41 42 44 45 50 41 32 28 29 24 15 10  7  6  7 10 15 24 29 28 32 41 50 45 44 42 41 41 42 43 44 44
  115  35 35 35 35 36 37 38 35 32 30 30 30 29 27 28 29 20 15 13 15 20 29 28 27 29 30 30 30 32 35 38 37 36 35 35 35 35
  120  30 30 30 29 28 27 26 26 26 27 31 34 33 29 25 26 34 34 29 34 34 26 25 29 33 34 31 27 26 26 26 27 28 29 30 30 30
  125  23 23 23 23 23 23 23 23 25 29 37 39 33 30 27 27 28 32 34 32 28 27 27 30 33 39 37 29 25 23 23 23 23 23 23 23 23
  130  22 22 22 22 22 23 23 23 26 30 44 34 30 31 35 35 31 29 29 29 31 35 35 31 30 34 44 30 26 23 23 23 22 22 22 22 22
  135  23 23 23 23 23 23 23 25 29 37 33 29 29 33 49 31 27 26 25 26 27 31 49 33 29 29 33 37 29 25 23 23 23 23 23 23 23
  140  23 23 23 23 24 25 28 32 34 30 27 27 29 36 41 32 29 28 27 28 29 32 41 36 29 27 27 30 34 32 28 25 24 23 23 23 23
  145  29 29 30 31 33 35 33 30 27 26 26 28 31 39 50 37 33 31 30 31 33 37 50 39 31 28 26 26 27 30 33 35 33 31 30 29 29
  150  33 33 32 31 30 28 28 27 27 28 29 31 34 37 36 32 30 28 27 28 30 32 36 37 34 31 29 28 27 27 28 28 30 31 32 33 33
  155  29 29 29 29 29 29 29 30 31 32 33 34 35 34 32 30 28 27 27 27 28 30 32 34 35 34 33 32 31 30 29 29 29 29 29 29 29
  160  33 33 33 33 34 34 35 35 36 37 37 36 35 33 32 31 29 29 29 29 29 31 32 33 35 36 37 37 36 35 35 34 34 33 33 33 33
  165  40 40 40 41 41 41 41 41 40 39 39 38 37 35 35 34 33 33 33 33 33 34 35 35 37 38 39 39 40 41 41 41 41 41 40 40 40
  170  46 46 45 45 45 45 44 44 43 43 42 42 41 41 40 40 40 39 39 39 40 40 40 41 41 42 42 43 43 44 44 45 45 45 45 46 46
  175  53 53 53 53 53 53 53 53 52 52 52 52 52 52 52 51 51 51 51 51 51 51 52 52 52 52 52 52 52 53 53 53 53 53 53 53 53
  180 123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123123

                 GAIN DEGRADATION IS
                   -9.268
```

Figure 4.24
Pattern 2. 1 Percent Error
Maximum Impact on Side Lobe 2

```
          BORESIGHT AT 90,90
 THETA                               PHI

       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0 121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121
   5  52 52 52 52 52 52 52 52 51 51 51 51 51 51 51 51 51 50 50 50 51 51 51 51 51 51 51 51 51 52 52 52 52 52 52 52 52
  10  45 45 45 44 44 44 43 43 42 42 41 41 40 40 39 39 39 39 39 39 39 39 39 40 40 41 41 42 42 43 43 44 44 44 45 45 45
  15  40 40 40 40 40 40 40 40 39 39 38 37 36 34 34 33 32 32 32 32 32 33 34 34 36 37 38 39 39 40 40 40 40 40 40 40 40
  20  32 32 32 33 33 33 34 35 36 36 36 35 34 32 31 29 28 28 28 28 28 29 31 32 34 35 36 36 36 35 34 33 33 33 32 32 32
  25  28 28 28 28 28 28 28 29 30 31 33 34 34 33 30 28 27 26 26 26 27 28 30 33 34 34 33 31 30 29 28 28 28 28 28 28 28
  30  29 29 28 28 27 26 26 26 26 26 28 31 34 35 33 30 27 26 25 26 27 30 33 35 34 31 28 26 26 26 26 26 27 28 28 29 29
  35  24 24 25 26 27 28 28 27 25 25 25 27 31 38 36 31 28 27 26 27 28 31 36 38 31 27 25 25 25 27 28 28 27 26 25 24 24
  40  20 20 20 20 21 22 23 26 28 27 25 25 28 35 36 28 25 24 24 24 25 28 36 35 28 25 25 27 28 26 23 22 21 20 20 20 20
  45  19 19 19 19 19 19 20 21 23 28 30 27 27 31 36 28 24 23 23 23 24 28 36 31 27 27 30 28 23 21 20 19 19 19 19 19 19
  50  19 19 19 18 18 18 19 20 22 24 31 32 28 28 29 29 27 26 25 26 27 29 29 28 28 32 31 24 22 20 19 18 18 18 19 19 19
  55  21 21 20 20 19 19 19 20 22 24 29 36 31 27 24 24 26 31 35 31 26 24 24 27 31 36 29 24 22 20 19 19 19 20 20 21 21
  60  26 26 25 24 23 23 23 22 23 24 28 32 31 26 23 23 30 34 27 34 30 23 23 26 31 32 28 24 23 22 23 23 23 24 25 26 26
  65  34 34 34 33 33 32 31 29 27 27 28 29 27 25 25 28 20 15 13 15 20 28 25 25 27 29 28 27 27 29 31 32 33 33 34 34 34
  70  37 37 35 34 33 33 34 37 42 42 35 29 26 26 23 15 10  7  6  7 10 15 23 26 26 29 35 42 42 37 34 33 33 34 35 37 37
  75  31 31 29 26 25 24 26 31 39 29 29 30 30 27 15  9  5  4  3  4  5  9 15 27 30 30 29 29 39 31 26 24 25 26 29 31 31
  80  37 35 31 27 25 23 24 29 30 26 27 30 30 19 10  5  3  2  2  2  3  5 10 19 30 30 27 26 30 29 24 23 25 27 31 35 37
  85  52 46 38 32 29 27 27 28 25 24 28 23 22 14  7  3  2  1  1  1  2  3  7 14 22 23 28 24 25 28 27 27 29 32 38 46 52
  90 125 54 42 35 31 29 28 26 23 24 26 21 19 13  6  3  2  1  0  1  2  3  6 13 19 21 26 24 23 26 28 29 31 35 42 54125
  95  52 46 38 32 29 27 27 28 25 24 28 23 22 14  7  3  2  1  1  1  2  3  7 14 22 23 28 24 25 28 27 27 29 32 38 46 52
 100  37 35 31 27 25 23 24 29 30 26 27 30 30 19 10  5  3  2  2  2  3  5 10 19 30 30 27 26 30 29 24 23 25 27 31 35 37
 105  31 31 29 26 25 24 26 31 39 29 29 30 30 27 15  9  5  4  3  4  5  9 15 27 30 30 29 29 39 31 26 24 25 26 29 31 31
 110  37 37 35 34 33 33 34 37 42 42 35 29 26 26 23 15 10  7  6  7 10 15 23 26 26 29 35 42 42 37 34 33 33 34 35 37 37
 115  34 34 34 33 33 32 31 29 27 27 28 29 27 25 25 28 20 15 13 15 20 28 25 25 27 29 28 27 27 29 31 32 33 33 34 34 34
 120  26 26 25 24 23 23 23 22 23 24 28 32 31 26 23 23 30 34 27 34 30 23 23 26 31 32 28 24 23 22 23 23 23 24 25 26 26
 125  21 21 20 20 19 19 19 20 22 24 29 36 31 27 24 24 26 31 35 31 26 24 24 27 31 36 29 24 22 20 19 19 19 20 20 21 21
 130  19 19 19 18 18 18 19 20 22 24 31 32 28 28 29 29 27 26 25 26 27 29 29 28 28 32 31 24 22 20 19 18 18 18 19 19 19
 135  19 19 19 19 19 19 20 21 23 28 30 27 27 31 36 28 24 23 23 23 24 28 36 31 27 27 30 28 23 21 20 19 19 19 19 19 19
 140  20 20 20 20 21 22 23 26 28 27 25 25 28 35 36 28 25 24 24 24 25 28 36 35 28 25 25 27 28 26 23 22 21 20 20 20 20
 145  24 24 25 26 27 28 28 27 25 25 25 27 31 38 36 31 28 27 26 27 28 31 36 38 31 27 25 25 25 27 28 28 27 26 25 24 24
 150  29 29 28 28 27 26 26 26 26 26 28 31 34 35 33 30 27 26 25 26 27 30 33 35 34 31 28 26 26 26 26 26 27 28 28 29 29
 155  28 28 28 28 28 28 28 29 30 31 33 34 34 33 30 28 27 26 26 26 27 28 30 33 34 34 33 31 30 29 28 28 28 28 28 28 28
 160  32 32 32 33 33 33 34 35 36 36 36 35 34 32 31 29 28 28 28 28 28 29 31 32 34 35 36 36 36 35 34 33 33 33 32 32 32
 165  40 40 40 40 40 40 40 40 39 39 38 37 36 34 34 33 32 32 32 32 32 33 34 34 36 37 38 39 39 40 40 40 40 40 40 40 40
 170  45 45 45 44 44 46 43 43 42 42 41 41 40 40 39 39 39 39 39 39 39 39 39 40 40 41 41 42 42 43 43 44 44 44 45 45 45
 175  52 52 52 52 52 52 52 52 51 51 51 51 51 51 51 51 51 50 50 50 51 51 51 51 51 51 51 51 51 52 52 52 52 52 52 52 52
 180 121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121121

                 GAIN DEGRADATION IS
                   -9.295
```

Figure 4.25
Pattern 2. 2 Percent Error
Maximum Impact on Side Lobe 2

```
          BORESIGHT AT 90,90
THETA                               PHI
          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0   134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134
    5    60 60 60 60 60 60 60 60 60 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 60 60 60 60 60 60 60 60 60
   10    46 46 46 46 46 46 46 47 47 47 47 48 48 48 49 49 49 49 49 49 49 49 49 48 48 48 47 47 47 47 46 46 46 46 46 46 46
   15    40 40 40 40 39 39 39 39 39 39 39 40 40 41 41 42 42 43 43 43 42 42 41 41 40 40 39 39 39 39 39 39 39 40 40 40 40
   20    39 39 39 38 38 37 37 36 35 35 35 35 35 36 37 38 39 39 39 39 39 38 37 36 35 35 35 35 35 36 37 37 38 38 39 39 39
   25    46 46 45 43 42 40 38 37 35 34 33 32 32 33 34 36 38 39 40 39 38 36 34 33 32 32 33 34 35 37 38 40 42 43 45 46 46
   30    51 51 53 56 64 55 47 43 39 36 34 32 31 32 33 36 41 49 51 49 41 36 33 32 31 32 34 36 39 43 47 55 64 56 53 51 51
   35    43 43 43 43 44 46 48 51 48 42 37 34 32 32 34 38 43 39 37 39 43 38 34 32 32 34 37 42 48 51 48 46 44 43 43 43 43
   40    39 40 40 41 43 44 45 45 45 44 41 38 35 34 35 37 35 32 31 32 35 37 35 34 35 38 41 44 45 45 45 44 43 41 40 40 39
   45    37 37 38 40 42 45 48 49 46 43 41 40 38 37 38 39 36 32 31 32 36 39 38 37 38 40 41 43 46 49 48 45 42 40 38 37 37
   50    34 34 34 35 37 39 40 41 41 41 41 40 38 37 36 39 44 39 36 39 44 39 36 37 38 40 41 41 41 41 40 39 37 35 34 34 34
   55    35 35 35 35 35 35 34 34 34 35 37 39 38 34 32 30 30 31 31 31 30 30 32 34 38 39 37 35 34 34 34 35 35 35 35 35 35
   60    47 48 50 57 50 42 37 33 32 33 35 36 35 32 31 32 40 36 32 36 40 32 31 32 35 36 35 33 32 33 37 42 50 57 50 48 47
   65    38 38 38 37 36 35 34 33 33 34 36 34 31 30 35 29 20 16 15 16 20 29 35 30 31 34 36 34 33 33 34 35 36 37 38 38 38
   70    42 41 40 38 36 33 31 30 30 32 42 34 28 29 24 16 11  8  8  8 11 16 24 29 28 34 42 32 30 30 31 33 36 38 40 41 42
   75    43 42 40 38 36 35 33 30 28 29 37 34 30 28 17 10  7  5  4  5  7 10 17 28 30 34 37 29 28 30 33 35 36 38 40 42 43
   80    47 46 42 38 36 37 39 33 28 29 45 29 31 21 11  7  5  3  3  3  5  7 11 21 31 29 45 29 28 33 39 37 36 38 42 46 47
   85    61 55 48 42 40 42 49 33 29 31 35 24 26 16  8  5  4  2  1  2  4  5  8 16 26 24 35 31 29 33 49 42 40 42 48 55 61
   90   137 63 52 45 43 47 43 32 28 32 31 23 24 14  7  4  3  1  0  1  3  4  7 14 24 23 31 32 28 32 43 47 43 45 52 63137
   95    61 55 48 42 40 42 49 33 29 31 35 24 26 16  8  5  4  2  1  2  4  5  8 16 26 24 35 31 29 33 49 42 40 42 48 55 61
  100    47 46 42 38 36 37 39 33 28 29 45 29 31 21 11  7  5  3  3  3  5  7 11 21 31 29 45 29 28 33 39 37 36 38 42 46 47
  105    43 42 40 38 36 35 33 30 28 29 37 34 30 28 17 10  7  5  4  5  7 10 17 28 30 34 37 29 28 30 33 35 36 38 40 42 43
  110    42 41 40 38 36 33 31 30 30 32 42 34 28 29 24 16 11  8  8  8 11 16 24 29 28 34 42 32 30 30 31 33 36 38 40 41 42
  115    38 38 38 37 36 35 34 33 33 34 36 34 31 30 35 29 20 16 15 16 20 29 35 30 31 34 36 34 33 33 34 35 36 37 38 38 38
  120    47 48 50 57 50 42 37 33 32 33 35 36 35 32 31 32 40 36 32 36 40 32 31 32 35 36 35 33 32 33 37 42 50 57 50 48 47
  125    35 35 35 35 35 35 34 34 34 35 37 39 38 34 32 30 30 31 31 31 30 30 32 34 38 39 37 35 34 34 34 35 35 35 35 35 35
  130    34 34 34 35 37 39 40 41 41 41 41 40 38 37 36 39 44 39 36 39 44 39 36 37 38 40 41 41 41 41 40 39 37 35 34 34 34
  135    37 37 38 40 42 45 48 49 46 43 41 40 38 37 38 39 36 32 31 32 36 39 38 37 38 40 41 43 46 49 48 45 42 40 38 37 37
  140    39 40 40 41 43 44 45 45 45 44 41 38 35 34 35 37 35 32 31 32 35 37 35 34 35 38 41 44 45 45 45 44 43 41 40 40 39
  145    43 43 43 43 44 46 48 51 48 42 37 34 32 32 34 38 43 39 37 39 43 38 34 32 32 34 37 42 48 51 48 46 44 43 43 43 43
  150    51 51 53 56 64 55 47 43 39 36 34 32 31 32 33 36 41 49 51 49 41 36 33 32 31 32 34 36 39 43 47 55 64 56 53 51 51
  155    46 46 45 43 42 40 38 37 35 34 33 32 32 33 34 36 38 39 40 39 38 36 34 33 32 32 33 34 35 37 38 40 42 43 45 46 46
  160    39 39 39 38 38 37 37 36 35 35 35 35 35 36 37 38 39 39 39 39 39 38 37 36 35 35 35 35 35 36 37 37 38 38 39 39 39
  165    40 40 40 40 39 39 39 39 39 39 39 40 40 41 41 42 42 43 43 43 42 42 41 41 40 40 39 39 39 39 39 39 39 40 40 40 40
  170    46 46 46 46 46 46 46 47 47 47 47 48 48 48 49 49 49 49 49 49 49 49 49 48 48 48 47 47 47 47 46 46 46 46 46 46 46
  175    60 60 60 60 60 60 60 60 60 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 60 60 60 60 60 60 60 60 60
  180   134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134

               GAIN DEGRADATION IS
                 -9.214
```

Figure 4.26
Pattern 3. 1 Percent Error
Maximum Impact on the Main Beam

```
       BORESIGHT AT 90,90

THETA                           PHI

        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0   137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137
  5    63 63 63 63 64 64 64 64 65 65 65 65 66 66 66 66 66 67 67 67 66 66 66 66 66 65 65 65 65 64 64 64 64 63 63 63 63
 10    47 47 47 47 47 47 48 48 49 49 50 51 51 52 53 54 54 55 55 55 54 54 53 52 51 51 50 49 49 48 48 47 47 47 47 47 47
 15    40 40 40 40 39 39 39 39 40 40 40 41 42 43 45 46 47 48 48 48 47 46 45 43 42 41 40 40 40 39 39 39 39 40 40 40 40
 20    39 39 39 39 38 37 37 36 35 35 35 35 36 37 39 41 44 45 46 45 44 41 39 37 36 35 35 35 35 36 37 37 38 39 39 39 39
 25    49 48 47 45 43 41 39 37 35 34 33 32 33 33 35 38 43 48 49 48 43 38 35 33 33 32 33 34 35 37 39 41 43 45 47 48 49
 30    44 44 45 47 50 61 53 45 39 36 34 32 31 32 33 37 44 51 48 51 44 37 33 32 31 32 34 36 39 45 53 61 50 47 45 44 44
 35    38 39 39 39 40 41 42 45 47 42 37 34 32 32 33 36 39 37 36 37 39 36 33 32 32 34 37 42 47 45 42 41 40 39 39 39 38
 40    35 36 36 37 38 39 40 41 41 41 40 37 35 34 34 35 35 33 32 33 35 35 34 34 35 37 40 41 41 41 40 39 38 37 36 36 35
 45    34 34 34 35 37 39 41 44 43 40 38 37 37 37 37 38 37 35 33 35 37 38 37 37 37 37 38 40 43 44 41 39 37 35 34 34 34
 50    33 33 33 34 36 39 43 48 47 43 40 38 37 37 37 40 40 35 33 35 40 40 37 37 37 38 40 43 47 48 43 39 36 34 33 33 33
 55    32 32 32 32 33 34 35 36 37 38 40 41 38 34 32 30 30 30 29 30 30 30 32 34 38 41 40 38 37 36 35 34 33 32 32 32 32
 60    38 38 38 38 37 36 34 33 32 34 38 42 37 33 31 32 45 35 31 35 45 32 31 33 37 42 38 34 32 33 34 36 37 38 38 38 38
 65    55 54 51 47 43 39 35 33 32 33 38 37 31 29 33 28 20 16 15 16 20 28 33 29 31 37 38 33 32 33 35 39 43 47 51 54 55
 70    42 41 40 38 36 34 32 30 29 30 40 34 27 27 24 16 11  9  8  9 11 16 24 27 27 34 40 30 29 30 32 34 36 38 40 41 42
 75    41 40 38 36 35 34 32 29 26 27 35 32 27 28 17 10  7  5  5  5  7 10 17 28 27 32 35 27 26 29 32 34 35 36 38 40 41
 80    48 46 42 39 36 36 36 31 27 28 43 29 32 22 11  7  5  3  3  3  5  7 11 22 32 29 43 28 27 31 36 36 36 39 42 46 48
 85    64 58 50 45 43 47 43 32 29 31 35 25 28 16  8  5  4  2  1  2  4  5  8 16 28 25 35 31 29 32 43 47 43 45 50 58 64
 90   137 67 55 49 47 50 39 32 29 33 30 24 26 14  7  5  3  1  0  1  3  5  7 14 26 24 30 33 29 32 39 50 47 49 55 67137
 95    64 58 50 45 43 47 43 32 29 31 35 25 28 16  8  5  4  2  1  2  4  5  8 16 28 25 35 31 29 32 43 47 43 45 50 58 64
100    48 46 42 39 36 36 36 31 27 28 43 29 32 22 11  7  5  3  3  3  5  7 11 22 32 29 43 28 27 31 36 36 36 39 42 46 48
105    41 40 38 36 35 34 32 29 26 27 35 32 27 28 17 10  7  5  5  5  7 10 17 28 27 32 35 27 26 29 32 34 35 36 38 40 41
110    42 41 40 38 36 34 32 30 29 30 40 34 27 27 24 16 11  9  8  9 11 16 24 27 27 34 40 30 29 30 32 34 36 38 40 41 42
115    55 54 51 47 43 39 35 33 32 33 38 37 31 29 33 28 20 16 15 16 20 28 33 29 31 37 38 33 32 33 35 39 43 47 51 54 55
120    38 38 38 38 37 36 34 33 32 34 38 42 37 33 31 32 45 35 31 35 45 32 31 33 37 42 38 34 32 33 34 36 37 38 38 38 38
125    32 32 32 32 33 34 35 36 37 38 40 41 38 34 32 30 30 30 29 30 30 30 32 34 38 41 40 38 37 36 35 34 33 32 32 32 32
130    33 33 33 34 36 39 43 48 47 43 40 38 37 36 37 40 40 35 33 35 40 40 37 36 37 38 40 43 47 48 43 39 36 34 33 33 33
135    34 34 34 35 37 39 41 44 43 40 38 37 37 37 37 38 37 35 33 35 37 38 37 37 37 37 38 40 43 44 41 39 37 35 34 34 34
140    35 36 36 37 38 39 40 41 41 41 40 37 35 34 34 35 35 33 32 33 35 35 34 34 35 37 40 41 41 41 40 39 38 37 36 36 35
145    38 39 39 39 40 41 42 45 47 42 37 34 32 32 33 36 39 37 36 37 39 36 33 32 32 34 37 42 47 45 42 41 40 39 39 39 38
150    44 44 45 47 50 61 53 45 39 36 34 32 31 32 33 37 44 51 48 51 44 37 33 32 31 32 34 36 39 45 53 61 50 47 45 44 44
155    49 48 47 45 43 41 39 37 35 34 33 32 33 33 35 38 43 48 49 48 43 38 35 33 33 32 33 34 35 37 39 41 43 45 47 48 49
160    39 39 39 39 38 37 37 36 35 35 35 35 36 37 39 41 44 45 46 45 44 41 39 37 36 35 35 35 35 36 37 37 38 39 39 39 39
165    40 40 40 40 39 39 39 39 40 40 40 41 42 43 45 46 47 48 48 48 47 46 45 43 42 41 40 40 40 39 39 39 39 40 40 40 40
170    47 47 47 47 47 47 48 48 49 49 50 51 51 52 53 54 54 55 55 55 54 54 53 52 51 51 50 49 49 48 48 47 47 47 47 47 47
175    63 63 63 63 64 64 64 64 65 65 65 65 66 66 66 66 66 67 67 67 66 66 66 66 66 65 65 65 65 64 64 64 64 63 63 63 63
180   137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137137

                GAIN DEGRADATION IS
                  -9.115
```

Figure 4.27
Pattern 3. 2 Percent Error
Maximum Impact on the Main Beam

```
          BORESIGHT AT 90,90
THETA                                     PHI
          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0     133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133
   5      55 55 55 55 55 55 56 56 56 57 57 58 58 59 59 59 60 60 60 60 60 59 59 59 58 58 57 57 56 56 56 55 55 55 55 55 55
  10      37 37 37 38 38 38 38 39 39 40 41 42 43 44 45 46 47 48 48 48 47 46 45 44 43 42 41 40 39 39 38 38 38 38 37 37 37
  15      29 29 29 29 29 29 29 30 30 30 31 32 33 34 36 38 40 41 42 41 40 38 36 34 33 32 31 30 30 30 29 29 29 29 29 29 29
  20      28 28 28 28 27 27 26 25 25 25 25 25 26 28 30 32 35 38 39 38 35 32 30 28 26 25 25 25 25 25 26 27 27 28 28 28 28
  25      36 36 35 33 31 29 28 26 24 23 22 22 22 23 25 28 33 37 39 37 33 28 25 23 22 22 22 23 24 26 28 29 31 33 35 36 36
  30      39 40 41 43 45 43 37 32 28 25 23 22 22 22 23 27 33 44 40 44 34 27 23 22 22 22 23 25 28 32 37 43 45 43 41 40 39
  35      34 35 35 35 35 36 38 41 38 31 26 23 22 22 23 27 41 34 30 34 41 27 23 22 22 23 26 31 38 41 38 36 35 35 35 35 34
  40      36 36 36 36 36 36 36 36 37 38 33 28 25 24 25 31 41 28 25 28 41 31 25 24 25 28 33 38 37 36 36 36 36 36 36 36 36
  45      36 36 37 38 40 41 42 41 39 38 37 35 31 28 29 35 37 28 25 28 37 35 29 28 31 35 37 38 39 41 42 41 40 38 37 36 36
  50      31 31 31 31 32 33 34 35 37 39 38 38 36 33 31 33 42 37 34 37 42 33 31 33 36 38 38 39 37 35 34 33 32 31 31 31 31
  55      34 34 34 34 33 32 30 30 30 32 35 36 36 33 29 27 28 30 31 30 28 27 29 33 36 36 35 32 30 30 30 32 33 34 34 34 34
  60      36 36 37 38 40 40 35 31 29 30 32 33 32 30 27 27 29 28 26 28 29 27 27 30 32 33 32 30 29 31 35 40 40 38 37 36 36
  65      31 30 30 29 29 29 30 31 31 32 34 32 29 28 33 28 18 13 12 13 18 28 33 28 29 32 34 32 31 31 30 29 29 29 30 30 31
  70      37 36 35 33 31 30 28 28 29 31 39 34 29 31 24 15  9  6  5  6  9 15 24 31 29 34 39 31 29 28 28 30 31 33 35 36 37
  75      42 41 39 37 35 33 32 30 28 29 38 33 32 26 14  8  4  3  2  3  4  8 14 26 32 33 38 29 28 30 32 33 35 37 39 41 42
  80      44 42 39 35 33 32 35 34 29 30 39 26 28 18  9  4  2  1  1  1  2  4  9 18 28 26 39 30 29 34 35 32 33 35 39 42 44
  85      57 51 44 38 35 36 43 33 28 30 31 22 22 14  6  2  1  1  0  1  1  2  6 14 22 22 31 30 28 33 43 36 35 38 44 51 57
  90     135 59 47 41 38 40 44 30 26 30 28 20 21 12  5  2  1  0  0  0  1  2  5 12 21 20 28 30 26 30 44 40 38 41 47 59135
  95      57 51 44 38 35 36 43 33 28 30 31 22 22 14  6  2  1  1  0  1  1  2  6 14 22 22 31 30 28 33 43 36 35 38 44 51 57
 100      44 42 39 35 33 32 35 34 29 30 39 26 28 18  9  4  2  1  1  1  2  4  9 18 28 26 39 30 29 34 35 32 33 35 39 42 44
 105      42 41 39 37 35 33 32 30 28 29 38 33 32 26 14  8  4  3  2  3  4  8 14 26 32 33 38 29 28 30 32 33 35 37 39 41 42
 110      37 36 35 33 31 30 28 28 29 31 39 34 29 31 24 15  9  6  5  6  9 15 24 31 29 34 39 31 29 28 28 30 31 33 35 36 37
 115      31 30 30 29 29 29 30 31 31 32 34 32 29 28 33 28 18 13 12 13 18 28 33 28 29 32 34 32 31 31 30 29 29 29 30 30 31
 120      36 36 37 38 40 40 35 31 29 30 32 33 32 30 27 27 29 28 26 28 29 27 27 30 32 33 32 30 29 31 35 40 40 38 37 36 36
 125      34 34 34 34 33 32 30 30 30 32 35 36 36 33 29 27 28 30 31 30 28 27 29 33 36 36 35 32 30 30 30 32 33 34 34 34 34
 130      31 31 31 31 32 33 34 35 37 39 38 38 36 33 31 33 42 37 34 37 42 33 31 33 36 38 38 39 37 35 34 33 32 31 31 31 31
 135      36 36 37 38 40 41 42 41 39 38 37 35 31 28 29 35 37 28 25 28 37 35 29 28 31 35 37 38 39 41 42 41 40 38 37 36 36
 140      36 36 36 36 36 36 36 36 37 38 33 28 25 24 25 31 41 28 25 28 41 31 25 24 25 28 33 38 37 36 36 36 36 36 36 36 36
 145      34 35 35 35 35 36 38 41 38 31 26 23 22 22 23 27 41 34 30 34 41 27 23 22 22 23 26 31 38 41 38 36 35 35 35 35 34
 150      39 40 41 43 45 43 37 32 28 25 23 22 22 22 23 27 33 44 40 44 34 27 23 22 22 22 23 25 28 32 37 43 45 43 41 40 39
 155      36 36 35 33 31 29 28 26 24 23 22 22 22 23 25 28 33 37 39 37 33 28 25 23 22 22 22 23 24 26 28 29 31 33 35 36 36
 160      28 28 28 28 27 27 26 25 25 25 25 25 26 28 30 32 35 38 39 38 35 32 30 28 26 25 25 25 25 25 26 27 27 28 28 28 28
 165      29 29 29 29 29 29 29 30 30 30 31 32 33 34 36 38 40 41 42 41 40 38 36 34 33 32 31 30 30 30 29 29 29 29 29 29 29
 170      37 37 37 38 38 38 38 39 39 40 41 42 43 44 45 46 47 48 48 48 47 46 45 44 43 42 41 40 39 39 38 38 38 38 37 37 37
 175      55 55 55 55 55 55 56 56 56 57 57 58 58 59 59 59 60 60 60 60 60 59 59 59 58 58 57 57 56 56 56 55 55 55 55 55 55
 180     133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133133

                   GAIN DEGRADATION IS
                     -9.268
```

Figure 4.28
Pattern 3. 1 Percent Error
Maximum Impact on Side Lobe 1

```
         BORESIGHT AT 90,90
THETA                              PHI
        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0   134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134
   5    54 54 54 54 55 55 56 56 57 58 59 60 61 62 63 63 64 64 64 64 64 63 63 62 61 60 59 58 57 56 56 55 55 54 54 54 54
  10    34 34 34 34 35 35 35 36 37 38 39 40 42 44 46 49 51 52 53 52 51 49 46 44 42 40 39 38 37 36 35 35 35 34 34 34 34
  15    26 26 26 25 25 25 26 26 26 27 28 29 30 32 35 38 42 45 46 45 42 38 35 32 30 29 28 27 26 26 26 25 25 25 26 26 26
  20    24 24 24 24 23 22 22 22 22 22 22 22 23 25 27 31 36 42 43 42 36 31 27 25 23 22 22 22 22 22 22 22 23 24 24 24 24
  25    32 32 31 29 27 25 23 22 21 20 19 19 20 21 22 26 33 41 40 41 33 26 22 21 20 19 19 20 21 22 23 25 27 29 31 32 32
  30    33 33 34 36 38 39 33 28 24 22 19 18 18 18 20 23 32 38 33 38 32 23 20 18 18 18 19 22 24 28 33 39 38 36 34 33 33
  35    29 29 29 29 30 31 33 36 33 27 22 20 18 18 20 23 35 30 27 30 35 23 20 18 18 20 22 27 33 36 33 31 30 29 29 29 29
  40    32 32 32 31 31 31 31 31 33 34 29 24 21 20 21 25 46 26 23 26 46 25 21 20 21 24 29 34 33 31 31 31 31 31 32 32 32
  45    34 34 35 36 36 37 37 35 34 34 34 31 26 24 24 29 41 26 24 26 40 29 24 24 26 31 34 34 34 35 37 37 36 36 35 34 34
  50    30 30 30 31 32 33 34 36 38 37 35 35 33 30 29 31 39 34 31 34 39 31 29 30 33 35 35 37 38 36 34 33 32 31 30 30 30
  55    33 33 33 33 32 31 30 30 31 33 35 35 35 32 28 27 28 31 32 31 28 27 28 32 35 35 35 33 31 30 30 31 32 33 33 33 33
  60    36 36 37 38 40 38 34 31 29 30 33 35 33 29 26 25 26 25 23 25 26 25 26 29 33 35 33 30 29 31 34 38 40 38 37 36 36
  65    30 30 29 29 29 29 29 29 30 31 36 35 30 28 31 27 18 13 11 13 18 27 31 28 30 35 36 31 30 29 29 29 29 29 29 30 30
  70    36 35 34 33 31 29 28 28 28 31 38 36 30 33 25 15  9  6  5  6  9 15 25 33 30 36 38 31 28 28 28 29 31 33 34 35 36
  75    42 41 39 37 35 33 32 30 29 30 38 32 33 26 14  8  4  2  2  2  4  8 14 26 33 32 38 30 29 30 32 33 35 37 39 41 42
  80    44 42 38 35 32 32 34 35 31 32 36 25 27 18  9  4  2  1  1  1  2  4  9 18 27 25 36 32 31 35 34 32 32 35 38 42 44
  85    57 51 43 38 35 35 40 35 29 33 29 21 22 13  5  2  2  1  1  1  2  2  5 13 22 21 29 33 29 35 40 35 35 38 43 51 57
  90   135 59 47 41 38 39 43 32 27 12 27 20 21 12  5  2  1  1  0  1  1  2  5 12 21 20 27 32 27 32 43 39 38 41 47 59135
  95    57 51 43 38 35 35 40 35 29 33 29 21 22 13  5  2  2  1  1  1  2  2  5 13 22 21 29 33 29 35 40 35 35 38 43 51 57
 100    44 42 38 35 32 32 34 35 31 32 36 25 27 18  9  4  2  1  1  1  2  4  9 18 27 25 36 32 31 35 34 32 32 35 38 42 44
 105    42 41 39 37 35 33 32 30 29 30 38 32 33 26 14  8  4  2  2  2  4  8 14 26 33 32 38 30 29 30 32 33 35 37 39 41 42
 110    36 35 34 33 31 29 28 28 28 31 38 36 30 33 25 15  9  6  5  6  9 15 25 33 30 36 38 31 28 28 28 29 31 33 34 35 36
 115    30 30 29 29 29 29 29 29 30 31 36 35 30 28 31 27 18 13 11 13 18 27 31 28 30 35 36 31 30 29 29 29 29 29 29 30 30
 120    36 36 37 38 40 38 34 31 29 30 33 35 33 29 26 25 26 25 23 25 26 25 26 29 33 35 33 30 29 31 34 38 40 38 37 36 36
 125    33 33 33 33 32 31 30 30 31 33 35 35 35 32 28 27 28 31 32 31 28 27 28 32 35 35 35 33 31 30 30 31 32 33 33 33 33
 130    30 30 30 31 32 33 34 36 38 37 35 35 33 30 29 31 39 34 31 34 39 31 29 30 33 35 35 37 38 36 34 33 32 31 30 30 30
 135    34 34 35 36 36 37 37 35 34 34 34 31 26 24 24 29 41 26 24 26 40 29 24 24 26 31 34 34 34 35 37 37 36 36 35 34 34
 140    32 32 32 31 31 31 31 31 33 34 29 24 21 20 21 25 46 26 23 26 46 25 21 20 21 24 29 34 33 31 31 31 31 31 32 32 32
 145    29 29 29 29 30 31 33 36 33 27 22 20 18 18 20 23 35 30 27 30 35 23 20 18 18 20 22 27 33 36 33 31 30 29 29 29 29
 150    33 33 34 36 38 39 33 28 24 22 19 18 18 18 20 23 32 38 33 38 32 23 20 18 18 19 19 22 24 28 33 39 38 36 34 33 33
 155    32 32 31 29 27 25 23 22 21 20 19 19 20 21 22 26 33 41 40 41 33 26 22 21 20 19 19 20 21 22 23 25 27 29 31 32 32
 160    24 24 24 24 23 22 22 22 22 22 22 22 23 25 27 31 36 42 43 42 36 31 27 25 23 22 22 22 22 22 22 22 23 24 24 24 24
 165    26 26 26 25 25 25 26 26 26 27 28 29 30 32 35 38 42 45 46 45 42 38 35 32 30 29 29 27 26 26 26 25 25 25 26 26 26
 170    34 34 34 34 35 35 35 36 37 38 39 40 42 44 46 49 51 52 53 52 51 49 46 44 42 40 39 38 37 36 35 35 35 34 34 34 34
 175    54 54 54 54 55 55 56 56 57 58 59 60 61 62 63 63 64 64 64 64 64 63 63 62 61 60 59 58 57 56 56 55 55 54 54 54 54
 180   134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134134

                   GAIN DEGRADATION IS
                     -9.216
```

Figure 4.29
Pattern 3. 2 Percent Error
Maximum Impact on Side Lobe 1

```
          BORESIGHT AT 90,90
THETA                                 PHI
          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0  132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132
    5   57 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 57 57
   10   43 43 43 43 43 43 43 43 44 44 44 44 45 45 45 46 46 46 46 46 46 46 45 45 45 44 44 44 44 43 43 43 43 43 43 43 43
   15   37 37 37 37 37 37 36 36 36 36 36 37 37 37 38 39 39 39 40 39 39 39 38 37 37 37 36 36 36 36 36 37 37 37 37 37 37
   20   37 37 36 36 35 35 34 33 33 32 32 32 32 33 33 34 35 36 36 36 35 34 33 33 32 32 32 32 33 33 34 35 35 36 36 37 37
   25   41 41 40 39 38 37 36 34 33 31 30 30 29 30 31 32 34 35 36 35 34 32 31 30 29 30 30 31 33 34 36 37 38 39 40 41 41
   30   50 50 50 49 47 44 41 39 36 34 31 30 29 29 30 32 36 42 45 42 36 32 30 29 29 30 31 34 36 39 41 44 47 49 50 50 50
   35   51 51 52 54 57 65 59 51 45 40 35 32 31 30 32 36 43 38 35 38 43 36 32 30 31 32 35 40 45 51 59 65 57 54 52 51 51
   40   43 43 44 45 46 47 48 49 55 57 44 38 34 34 36 39 33 29 28 29 33 39 36 34 34 38 44 57 55 49 48 47 46 45 44 43 43
   45   36 37 38 39 42 45 46 45 47 53 49 42 38 38 41 42 32 28 27 28 32 42 41 38 38 42 49 53 47 45 46 45 42 39 38 37 36
   50   30 30 30 31 33 35 38 43 47 49 46 41 38 36 37 40 42 35 33 35 42 40 37 36 38 41 46 49 47 43 38 35 33 31 30 30 30
   55   32 32 32 32 31 31 31 31 32 33 35 36 35 33 30 29 29 29 30 29 29 29 30 33 35 36 35 33 32 31 31 31 31 32 32 32 32
   60   37 38 38 39 40 37 33 30 28 28 29 31 32 31 29 29 33 35 32 35 33 29 29 31 32 31 29 28 28 30 33 37 40 39 38 38 37
   65   28 28 28 27 27 27 27 27 28 28 29 30 30 30 39 28 19 15 14 15 19 28 39 30 30 30 29 28 28 27 27 27 27 27 28 28 28
   70   31 30 29 27 26 24 23 23 24 27 32 34 31 32 23 15 10  7  6  7 10 15 23 32 31 34 32 27 24 23 23 24 26 27 29 30 31
   75   37 36 34 32 29 27 24 23 23 23 27 35 38 26 15  9  5  4  3  4  5  9 15 26 38 35 27 23 23 23 24 27 29 32 34 36 37
   80   47 45 41 38 35 32 29 25 23 23 27 28 27 18  9  5  3  2  2  2  3  5  9 18 27 28 27 23 23 25 29 32 35 38 41 45 47
   85   65 59 51 47 47 44 32 25 22 23 31 23 21 14  6  3  2  2  1  2  2  3  6 14 21 23 31 23 22 25 32 44 47 47 51 59 65
   90  138 69 57 52 52 40 30 24 22 23 34 22 20 13  5  2  2  1  0  1  2  2  5 13 20 22 34 23 22 24 30 40 52 52 57 69138
   95   65 59 51 47 47 44 32 25 22 23 31 23 21 14  6  3  2  2  1  2  2  3  6 14 21 23 31 23 22 25 32 44 47 47 51 59 65
  100   47 45 41 38 35 32 29 25 23 23 27 28 27 18  9  5  3  2  2  2  3  5  9 18 27 28 27 23 23 25 29 32 35 38 41 45 47
  105   37 36 34 32 29 27 24 23 23 23 27 35 38 26 15  9  5  4  3  4  5  9 15 26 38 35 27 23 23 23 24 27 29 32 34 36 37
  110   31 30 29 27 26 24 23 23 24 27 32 34 31 32 23 15 10  7  6  7 10 15 23 32 31 34 32 27 24 23 23 24 26 27 29 30 31
  115   28 28 28 27 27 27 27 27 28 28 29 30 30 30 39 28 19 15 14 15 19 28 39 30 30 30 29 28 28 27 27 27 27 27 28 28 28
  120   37 38 38 39 40 37 33 30 28 28 29 31 32 31 29 29 33 35 32 35 33 29 29 31 32 31 29 28 28 30 33 37 40 39 38 38 37
  125   32 32 32 32 31 31 31 31 32 33 35 36 35 33 30 29 29 29 30 29 29 29 30 33 35 36 35 33 32 31 31 31 31 32 32 32 32
  130   30 30 30 31 33 35 38 43 47 49 46 41 38 36 37 40 42 35 33 35 42 40 37 36 38 41 46 49 47 43 38 35 33 31 30 30 30
  135   36 37 38 39 42 45 46 45 47 53 49 42 38 38 41 42 32 28 27 28 32 42 41 38 38 42 49 53 47 45 46 45 42 39 38 37 36
  140   43 43 44 45 46 47 48 49 55 57 44 38 34 34 36 39 33 29 28 29 33 39 36 34 34 38 44 57 55 49 48 47 46 45 44 43 43
  145   51 51 52 54 57 65 59 51 45 40 35 32 31 30 32 36 43 38 35 38 43 36 32 30 31 32 35 40 45 51 59 65 57 54 52 51 51
  150   50 50 50 49 47 44 41 39 36 34 31 30 29 29 30 32 36 42 45 42 36 32 30 29 29 30 31 34 36 39 41 44 47 49 50 50 50
  155   41 41 40 39 38 37 36 34 33 31 30 30 29 30 31 32 34 35 36 35 34 32 31 30 29 30 30 31 33 34 36 37 38 39 40 41 41
  160   37 37 36 36 35 35 34 33 33 32 32 32 32 33 33 34 35 36 36 36 35 34 33 33 32 32 32 32 33 33 34 35 35 36 36 37 37
  165   37 37 37 37 37 37 36 36 36 36 36 37 37 37 38 39 39 39 40 39 39 39 38 37 37 37 36 36 36 36 36 37 37 37 37 37 37
  170   43 43 43 43 43 43 43 43 44 44 44 44 45 45 45 46 46 46 46 46 46 46 45 45 45 44 44 44 44 43 43 43 43 43 43 43 43
  175   57 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 57 57
  180  132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132132

                    GAIN DEGRADATION IS
                      -9.351
```

Figure 4.30
Pattern 3. 1 Percent Error
Maximum Impact on Side Lobe 2

```
        BORESIGHT AT 90,90
THETA                           PHI

        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0  129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129
   5   54 54 54 54 54 54 54 54 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 54 54 54 54 54 54 54 54
  10   41 41 41 41 41 41 41 41 41 41 42 42 42 42 43 43 43 43 43 43 43 43 43 42 42 42 42 41 41 41 41 41 41 41 41 41 41
  15   35 35 35 35 35 35 34 34 34 34 34 34 35 35 36 36 36 37 37 37 36 36 36 35 35 34 34 34 34 34 34 35 35 35 35 35 35
  20   36 36 35 35 34 33 33 32 31 30 30 30 30 30 31 32 32 33 33 33 32 32 31 30 30 30 30 30 31 32 33 33 34 35 35 36 36
  25   41 41 40 39 38 37 35 33 31 30 29 28 27 28 28 30 31 32 33 32 31 30 28 29 27 28 29 30 31 33 35 37 38 39 40 41 41
  30   49 49 49 49 47 45 42 39 35 32 30 28 27 27 28 30 33 38 40 38 33 30 28 27 27 28 30 32 35 39 42 45 47 49 49 49 49
  35   60 61 63 66 71 72 61 51 44 38 34 31 29 29 30 34 41 37 34 37 41 34 30 29 29 31 34 38 44 51 61 72 71 66 63 61 60
  40   39 39 40 40 40 41 42 44 51 53 41 36 33 32 34 36 31 27 26 27 31 36 34 32 33 36 41 53 51 44 42 41 40 40 40 39 39
  45   33 34 35 37 40 42 40 39 41 47 50 39 36 36 40 36 29 25 24 25 29 36 40 36 36 39 50 47 41 39 40 42 40 37 35 34 33
  50   25 25 26 27 29 31 35 43 53 58 49 40 36 35 36 43 37 30 28 30 37 43 36 35 36 40 49 58 53 43 35 31 29 27 26 25 25
  55   28 28 27 27 27 28 28 28 30 32 34 36 34 31 28 27 28 28 28 28 28 27 28 31 34 36 34 32 30 28 28 28 27 27 27 28 28
  60   33 33 34 34 35 34 30 27 25 25 27 30 31 30 27 26 30 36 34 36 30 26 27 30 31 30 27 25 25 27 30 34 35 34 34 33 33
  65   24 24 23 23 22 22 22 23 24 25 27 29 29 30 38 28 19 14 13 14 19 28 38 30 29 29 27 25 24 23 22 22 22 23 23 24 24
  70   26 25 24 23 22 21 20 20 20 22 26 33 31 32 22 14  9  6  5  6  9 14 22 32 31 33 26 22 20 20 20 21 22 23 24 25 26
  75   32 31 29 26 24 22 20 19 18 19 22 28 34 23 13  8  4  3  2  3  4  8 13 23 34 28 22 19 18 19 20 22 24 26 29 31 32
  80   42 41 37 33 29 26 23 21 18 18 22 23 22 16  8  4  2  2  1  2  2  4  8 16 22 23 22 18 18 21 23 26 29 33 37 41 42
  85   64 58 50 43 37 30 24 20 18 18 22 22 18 12  5  2  1  1  0  1  1  2  5 12 18 22 22 18 18 20 24 30 37 43 50 58 64
  90  127 61 49 41 34 28 22 19 17 19 24 21 17 11  4  1  1  1  0  1  1  1  4 11 17 21 24 18 17 19 22 28 34 41 49 61127
  95   64 58 50 43 37 30 24 20 18 18 22 22 18 12  5  2  1  1  0  1  1  2  5 12 18 22 22 18 18 20 24 30 37 43 50 58 64
 100   42 41 37 33 29 26 23 21 18 18 22 23 22 16  8  4  2  2  1  2  2  4  8 16 22 23 22 18 18 21 23 26 29 33 37 41 42
 105   32 31 29 26 24 22 20 19 18 19 22 28 34 23 13  8  4  3  2  3  4  8 13 23 34 28 22 19 18 19 20 22 24 26 29 31 32
 110   26 25 24 23 22 21 20 20 20 22 26 33 31 32 22 14  9  6  5  6  9 14 22 32 31 33 26 22 20 20 20 21 22 23 24 25 26
 115   24 24 23 23 22 22 22 23 24 25 27 29 29 30 38 28 19 14 13 14 19 28 38 30 29 29 27 25 24 23 22 22 22 23 23 24 24
 120   33 33 34 34 35 34 30 27 25 25 27 30 31 30 27 26 30 36 34 36 30 26 27 30 31 30 27 25 25 27 30 34 35 34 34 33 33
 125   28 28 27 27 27 28 28 28 30 32 34 36 34 31 28 27 28 28 28 28 28 27 28 31 34 36 34 32 30 28 28 28 27 27 27 28 28
 130   25 25 26 27 29 31 35 43 53 58 49 40 36 35 36 43 37 30 28 30 37 43 36 35 36 40 49 58 53 43 35 31 29 27 26 25 25
 135   33 34 35 37 40 42 40 39 41 47 50 39 36 36 40 36 29 25 24 25 29 36 40 36 36 39 50 47 41 39 40 42 40 37 35 34 33
 140   39 39 40 40 40 41 42 44 51 53 41 36 33 32 34 36 31 27 26 27 31 36 34 32 33 36 41 53 51 44 42 41 40 40 40 39 39
 145   60 61 63 66 71 72 61 51 44 38 34 31 29 29 30 34 41 37 34 37 41 34 30 29 29 31 34 38 44 51 61 72 71 66 63 61 60
 150   49 49 49 49 47 45 42 39 35 32 30 28 27 27 28 30 33 38 40 38 33 30 28 27 27 28 30 32 35 39 42 45 47 49 49 49 49
 155   41 41 40 39 38 37 35 33 31 30 29 28 27 28 28 30 31 32 33 32 31 30 28 28 27 28 29 30 31 33 35 37 38 39 40 41 41
 160   36 36 35 35 34 33 33 32 31 30 30 30 30 30 31 32 32 33 33 33 32 32 31 30 30 30 30 30 31 32 33 33 34 35 35 36 36
 165   35 35 35 35 35 35 34 34 34 34 34 34 35 35 36 36 36 37 37 37 36 36 36 35 35 34 34 34 34 34 34 35 35 35 35 35 35
 170   41 41 41 41 41 41 41 41 41 41 42 42 42 42 43 43 43 43 43 43 43 43 43 42 42 42 42 41 41 41 41 41 41 41 41 41 41
 175   54 54 54 54 54 54 54 54 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 54 54 54 54 54 54 54 54
 180  129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129129

                GAIN DEGRADATION IS
                  -9.390
```

Figure 4.31
Pattern 3. 2 Percent Error
Maximum Impact on Side Lobe 2

```
          BORESIGHT AT 90,90
THETA                              PHI
       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0 128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128
   5  56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56
  10  43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43
  15  37 37 37 37 37 37 36 36 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 36 36 36 37 37 37 37 37 37
  20  33 33 33 33 33 33 33 33 32 32 32 32 32 33 33 34 34 34 34 34 34 34 33 33 32 32 32 32 32 33 33 33 33 33 33 33 33
  25  29 29 29 29 29 30 30 30 30 30 30 29 30 30 31 32 33 33 33 33 33 32 31 30 30 29 30 30 30 30 30 30 29 29 29 29 29
  30  26 26 26 26 26 26 27 27 28 29 29 29 28 29 30 33 35 36 36 36 35 33 30 29 28 29 29 29 28 27 27 26 26 26 26 26 26
  35  27 27 26 26 26 25 25 25 25 26 28 29 29 29 31 36 56 38 35 38 56 36 31 29 29 29 28 26 25 25 25 25 26 26 26 27 27
  40  29 29 29 28 28 27 26 25 25 25 26 28 30 31 33 38 34 29 27 29 34 38 33 31 30 28 26 25 25 25 26 27 28 28 29 29 29
  45  30 30 30 30 30 29 28 27 26 26 26 28 31 33 35 41 33 27 25 27 33 41 35 33 31 28 26 26 26 27 28 29 30 30 30 30 30
  50  29 29 29 29 29 29 28 28 28 28 28 29 30 32 32 35 39 31 29 31 39 35 32 32 30 29 28 28 28 28 28 29 29 29 29 29 29
  55  32 32 32 31 31 30 29 28 28 28 28 29 29 29 28 27 28 30 30 30 28 27 28 29 29 29 28 28 28 28 29 30 31 31 32 32 32
  60  42 42 44 47 53 43 36 32 30 29 28 27 27 26 26 27 32 34 31 34 32 27 26 26 27 27 28 29 30 32 36 43 53 47 44 42 42
  65  35 35 35 34 34 34 35 36 36 34 30 27 25 24 29 31 20 15 14 15 20 31 29 24 25 27 30 34 36 36 35 34 34 34 35 35 35
  70  39 39 38 36 34 32 31 31 33 41 37 27 24 25 23 16 10  7  6  7 10 16 23 25 24 27 37 41 33 31 31 32 34 36 38 39 39
  75  44 43 41 38 37 35 34 32 31 34 42 28 27 25 15  9  6  4  3  4  6  9 15 25 27 28 42 34 31 32 34 35 37 38 41 43 44
  80  47 45 41 38 35 36 40 36 30 32 40 26 30 20 10  5  3  2  2  2  3  5 10 20 30 26 40 32 30 36 40 36 35 38 41 45 47
  85  58 52 44 39 36 37 52 33 28 30 33 23 24 15  7  3  2  2  1  2  2  3  7 15 24 23 33 30 28 33 52 37 36 39 44 52 58
  90 131 59 47 40 37 38 43 31 26 29 31 21 22 14  6  3  2  1  0  1  2  3  6 14 22 21 31 29 26 31 43 38 37 40 47 59131
  95  58 52 44 39 36 37 52 33 28 30 33 23 24 15  7  3  2  2  1  2  2  3  7 15 24 23 33 30 28 33 52 37 36 39 44 52 58
 100  47 45 41 38 35 36 40 36 30 32 40 26 30 20 10  5  3  2  2  2  3  5 10 20 30 26 40 32 30 36 40 36 35 38 41 45 47
 105  44 43 41 38 37 35 34 32 31 34 42 28 27 25 15  9  6  4  3  4  6  9 15 25 27 28 42 34 31 32 34 35 37 38 41 43 44
 110  39 39 38 36 34 32 31 31 33 41 37 27 24 25 23 16 10  7  6  7 10 16 23 25 24 27 37 41 33 31 31 32 34 36 38 39 39
 115  35 35 35 34 34 34 35 36 36 34 30 27 25 24 29 31 20 15 14 15 20 31 29 24 25 27 30 34 36 36 35 34 34 34 35 35 35
 120  42 42 44 47 53 43 36 32 30 29 28 27 27 26 26 27 32 34 31 34 32 27 26 26 27 27 28 29 30 32 36 43 53 47 44 42 42
 125  32 32 32 31 31 30 29 28 28 28 28 29 29 29 28 27 28 30 30 30 28 27 28 29 29 29 28 28 28 28 29 30 31 31 32 32 32
 130  29 29 29 29 29 29 28 28 28 28 28 29 30 32 32 35 39 31 29 31 39 35 32 32 30 29 28 28 28 28 28 29 29 29 29 29 29
 135  30 30 30 30 30 29 28 27 26 26 26 28 31 33 35 41 33 27 25 27 33 41 35 33 31 28 26 26 26 27 28 29 30 30 30 30 30
 140  29 29 29 28 28 27 26 25 25 25 26 28 30 31 33 38 34 29 27 29 34 38 33 31 30 28 26 25 25 25 26 27 28 28 29 29 29
 145  27 27 26 26 26 25 25 25 25 26 28 29 29 29 31 36 56 38 35 38 56 36 31 29 29 29 28 26 25 25 25 25 26 26 26 27 27
 150  26 26 26 26 26 26 27 27 28 29 29 29 28 29 30 33 35 36 36 36 35 33 30 29 28 29 29 29 28 27 27 26 26 26 26 26 26
 155  29 29 29 29 29 30 30 30 30 30 30 29 30 30 31 32 33 33 33 33 33 32 31 30 30 29 30 30 30 30 30 30 29 29 29 29 29
 160  33 33 33 33 33 33 33 33 32 32 32 32 32 33 33 34 34 34 34 34 34 34 33 33 32 32 32 32 32 33 33 33 33 33 33 33 33
 165  37 37 37 37 37 37 36 36 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 36 36 36 37 37 37 37 37 37
 170  43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43
 175  56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56
 180 128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128

              GAIN DEGRADATION IS
                -9.230
```

Figure 4.32
Pattern 3. 1 Percent Error
Maximum Impact on the Null

```
          BORESIGHT AT 90,90
THETA                                  PHI
          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0    127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127
   5     56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56
  10     44 44 44 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 44 44 44
  15     36 36 36 36 36 36 36 37 37 37 37 37 37 37 37 37 37 36 36 36 37 37 37 37 37 37 37 37 37 37 36 36 36 36 36 36 36
  20     29 29 29 30 30 31 31 31 32 32 32 32 33 33 33 33 33 33 32 33 33 33 33 33 33 32 32 32 32 31 31 31 30 30 29 29 29
  25     23 23 23 23 23 24 25 26 27 28 29 29 30 30 31 32 32 31 31 31 32 32 31 30 30 29 29 28 27 26 25 24 23 23 23 23 23
  30     21 21 21 21 21 21 21 22 23 24 25 27 28 29 31 33 35 34 33 34 35 33 31 29 28 27 25 24 23 22 21 21 21 21 21 21 21
  35     22 22 22 21 21 20 20 20 20 21 23 25 27 29 31 37 49 34 32 34 49 37 31 29 27 25 23 21 20 20 20 20 21 21 22 22 22
  40     24 24 23 23 23 22 21 20 20 20 21 23 26 31 34 38 33 27 26 27 33 38 34 31 26 23 21 20 20 20 21 22 23 23 23 24 24
  45     26 26 25 25 24 23 23 22 21 21 21 23 25 30 36 45 31 25 24 25 31 45 36 30 25 23 21 21 21 22 23 23 24 25 25 26 26
  50     26 26 26 25 25 25 24 23 23 23 23 23 25 28 31 34 34 28 26 28 34 34 31 28 25 23 23 23 23 23 24 25 25 25 26 26 26
  55     28 28 28 28 27 27 26 25 24 24 24 24 25 26 26 26 27 28 28 28 27 26 26 26 25 24 24 24 24 25 26 27 27 28 28 28 28
  60     36 36 36 36 36 35 33 30 28 26 25 24 23 23 24 26 31 31 30 31 31 26 24 23 23 24 25 26 28 30 33 35 36 36 36 36 36
  65     38 38 38 37 37 38 41 45 38 31 27 24 23 23 25 30 20 16 14 16 20 30 25 23 23 24 27 31 38 45 41 38 37 37 38 38 38
  70     40 40 38 37 35 34 33 34 38 44 29 24 22 23 22 15 10  8  7  8 10 15 22 23 22 24 29 44 38 34 33 34 35 37 38 40 40
  75     45 44 42 40 38 37 35 34 34 43 31 24 23 23 15  9  6  4  3  4  6  9 15 23 23 24 31 43 34 34 35 37 38 40 42 44 45
  80     49 47 44 40 39 41 50 35 31 34 31 23 27 20 10  5  3  2  2  2  3  5 10 20 27 23 31 34 31 35 50 41 39 40 44 47 49
  85     59 53 45 40 37 38 39 30 26 29 31 22 23 16  7  3  2  2  1  2  2  3  7 16 23 22 31 29 26 30 39 38 37 40 45 53 59
  90    130 59 47 40 37 36 35 28 25 27 30 21 21 15  6  3  2  1  0  1  2  3  6 15 21 21 30 27 25 28 35 36 37 40 47 59130
  95     59 53 45 40 37 38 39 30 26 29 31 22 23 16  7  3  2  2  1  2  2  3  7 16 23 22 31 29 26 30 39 38 37 40 45 53 59
 100     49 47 44 40 39 41 50 35 31 34 31 23 27 20 10  5  3  2  2  2  3  5 10 20 27 23 31 34 31 35 50 41 39 40 44 47 49
 105     45 44 42 40 38 37 35 34 34 43 31 24 23 23 15  9  6  4  3  4  6  9 15 23 23 24 31 43 34 34 35 37 38 40 42 44 45
 110     40 40 38 37 35 34 33 34 38 44 29 24 22 23 22 15 10  8  7  8 10 15 22 23 22 24 29 44 38 34 33 34 35 37 38 40 40
 115     38 38 38 37 37 38 41 45 38 31 27 24 23 23 25 30 20 16 14 16 20 30 25 23 23 24 27 31 38 45 41 38 37 37 38 38 38
 120     36 36 36 36 36 35 33 30 28 26 25 24 23 23 24 26 31 31 30 31 31 26 24 23 23 24 25 26 28 30 33 35 36 36 36 36 36
 125     28 28 28 28 27 27 26 25 24 24 24 24 25 26 26 26 27 28 28 28 27 26 26 26 25 24 24 24 24 25 26 27 27 28 28 28 28
 130     26 26 26 25 25 25 24 23 23 23 23 23 25 28 31 34 34 28 26 28 34 34 31 28 25 23 23 23 23 23 24 25 25 25 26 26 26
 135     26 26 25 25 24 23 23 22 21 21 21 23 25 30 36 45 31 25 24 25 31 45 36 30 25 23 21 21 21 22 23 23 24 25 25 26 26
 140     24 24 23 23 23 22 21 20 20 20 21 23 26 31 34 38 33 27 26 27 33 38 34 31 26 23 21 20 20 20 21 22 23 23 23 24 24
 145     22 22 22 21 21 20 20 20 20 21 23 25 27 29 31 37 49 34 32 34 49 37 31 29 27 25 23 21 20 20 20 20 21 21 22 22 22
 150     21 21 21 21 21 21 21 22 23 24 25 27 28 29 31 33 35 34 33 34 35 33 31 29 28 27 25 24 23 22 21 21 21 21 21 21 21
 155     23 23 23 23 23 24 25 26 27 28 29 29 30 30 31 32 32 31 31 31 32 32 31 30 30 29 29 28 27 26 25 24 23 23 23 23 23
 160     29 29 29 30 30 31 31 31 32 32 32 32 33 33 33 33 33 33 32 33 33 33 33 33 33 32 32 32 32 31 31 31 30 30 29 29 29
 165     36 36 36 36 36 36 36 37 37 37 37 37 37 37 37 37 37 36 36 36 37 37 37 37 37 37 37 37 37 37 36 36 36 36 36 36 36
 170     44 44 44 44 44 44 44 44 44 44 44 44 44 44 43 43 43 43 43 43 43 43 43 44 44 44 44 44 44 44 44 44 44 44 44 44 44
 175     56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56
 180    127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127

                  GAIN DEGRADATION IS
                    -9.146
```

Figure 4.33
Pattern 3. 2 Percent Error
Maximum Impact on the Null

```
          BORESIGHT AT 90,90

THETA                           PHI

         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125
    5   57 57 57 57 57 57 57 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 57 57 57 57 57 57 57 57
   10   45 45 45 45 45 45 45 46 46 46 46 45 45 44 44 44 43 43 43 43 43 44 44 44 45 45 46 46 46 46 45 45 45 45 45 45 45
   15   37 37 37 37 37 37 37 37 37 38 38 39 39 39 38 37 37 36 36 36 37 37 38 39 39 39 38 38 37 37 37 37 37 37 37 37 37
   20   33 33 33 33 33 33 32 32 32 32 32 33 34 34 34 34 33 32 32 32 33 34 34 34 34 33 32 32 32 32 32 33 33 33 33 33 33
   25   34 33 33 33 32 32 31 31 30 30 30 30 30 31 31 32 31 30 30 30 31 32 31 31 30 30 30 30 30 31 31 32 32 33 33 33 34
   30   50 49 45 41 37 35 33 31 30 30 30 29 29 29 30 31 31 30 30 30 31 31 30 29 29 29 30 30 30 31 33 35 37 41 45 49 50
   35   32 33 33 35 37 39 38 35 32 31 31 31 31 30 30 31 33 34 34 34 33 31 30 30 31 31 31 31 32 35 38 39 37 35 33 33 32
   40   33 33 33 33 33 33 34 34 33 32 32 34 35 32 31 31 36 42 42 42 36 31 31 32 35 34 32 32 33 34 34 33 33 33 33 33 33
   45   36 36 37 40 43 42 38 34 32 31 31 33 34 31 29 31 34 30 29 30 34 31 29 31 34 33 31 31 32 34 38 42 43 40 37 36 36
   50   32 32 33 34 37 41 47 40 35 33 33 34 34 31 30 32 32 29 27 29 32 32 30 31 34 34 33 33 35 40 47 41 37 34 33 32 32
   55   42 42 44 47 57 48 41 38 38 40 43 44 43 40 36 37 42 38 35 38 42 37 36 40 43 44 43 40 38 38 41 48 57 47 44 42 42
   60   35 35 35 34 32 31 30 30 33 44 37 29 25 21 20 21 23 19 17 19 23 21 20 21 25 29 37 44 33 30 30 31 32 34 35 35 35
   65   34 33 33 32 31 29 29 29 30 36 36 26 20 15 13 12 13 11 10 11 13 12 13 15 20 26 36 36 30 29 29 29 31 32 33 33 34
   70   35 35 34 33 32 32 33 36 39 42 39 29 20 13  9  7  7  7  6  7  7  7  9 13 20 29 39 42 39 36 33 32 32 33 34 35 35
   75   37 36 34 32 30 30 30 31 32 34 41 37 22 13  8  5  4  4  4  4  4  5  8 13 22 37 41 34 32 31 30 30 30 32 34 36 37
   80   44 42 38 34 31 30 29 29 28 29 35 49 25 14  7  4  3  3  3  3  3  4  7 14 25 49 35 29 28 29 29 30 31 34 38 42 44
   85   57 51 43 37 34 32 32 33 31 30 32 36 20 12  6  4  3  1  1  1  3  4  6 12 20 36 32 30 31 33 32 32 34 37 43 51 57
   90  130 57 45 39 34 33 33 38 35 30 31 34 18 10  6  4  3  1  0  1  3  4  6 10 18 34 31 30 35 38 33 33 34 39 45 57130
   95   57 51 43 37 34 32 32 33 31 30 32 36 20 12  6  4  3  1  1  1  3  4  6 12 20 36 32 30 31 33 32 32 34 37 43 51 57
  100   44 42 38 34 31 30 29 29 28 29 35 49 25 14  7  4  3  3  3  3  3  4  7 14 25 49 35 29 28 29 29 30 31 34 38 42 44
  105   37 36 34 32 30 30 30 31 32 34 41 37 22 13  8  5  4  4  4  4  4  5  8 13 22 37 41 34 32 31 30 30 30 32 34 36 37
  110   35 35 34 33 32 32 33 36 39 42 39 29 20 13  9  7  7  7  6  7  7  7  9 13 20 29 39 42 39 36 33 32 32 33 34 35 35
  115   34 33 33 32 31 29 29 29 30 36 36 26 20 15 13 12 13 11 10 11 13 12 13 15 20 26 36 36 30 29 29 29 31 32 33 33 34
  120   35 35 35 34 32 31 30 30 33 44 37 29 25 21 20 21 23 19 17 19 23 21 20 21 25 29 37 44 33 30 30 31 32 34 35 35 35
  125   42 42 44 47 57 48 41 38 38 40 43 44 43 40 36 37 42 38 35 38 42 37 36 40 43 44 43 40 38 38 41 48 57 47 44 42 42
  130   32 32 33 34 37 41 47 40 35 33 33 34 34 31 30 32 32 29 27 29 32 32 30 31 34 34 33 33 35 40 47 41 37 34 33 32 32
  135   36 36 37 40 43 42 38 34 32 31 31 33 34 31 29 31 34 30 29 30 34 31 29 31 34 33 31 31 32 34 38 42 43 40 37 36 36
  140   33 33 33 33 33 33 34 34 33 32 32 34 35 32 31 31 36 42 42 42 36 31 31 32 35 34 32 32 33 34 34 33 33 33 33 33 33
  145   32 33 33 35 37 39 38 35 32 31 31 31 31 30 30 31 33 34 34 34 33 31 30 30 31 31 31 31 32 35 38 39 37 35 33 33 32
  150   50 49 45 41 37 35 33 31 30 30 30 29 29 29 30 31 31 30 30 30 31 31 30 29 29 29 30 30 30 31 33 35 37 41 45 49 50
  155   34 33 33 33 32 32 31 31 30 30 30 30 30 31 31 32 31 30 30 30 31 32 31 31 30 30 30 30 30 31 31 32 32 33 33 33 34
  160   33 33 33 33 33 33 32 32 32 32 32 33 34 34 34 34 33 32 32 32 33 34 34 34 34 33 32 32 32 32 32 33 33 33 33 33 33
  165   37 37 37 37 37 37 37 37 37 38 38 39 39 39 38 37 37 36 36 36 37 37 38 39 39 39 38 38 37 37 37 37 37 37 37 37 37
  170   45 45 45 45 45 45 45 46 46 46 46 45 45 44 44 44 43 43 43 43 43 44 44 44 45 45 46 46 46 46 45 45 45 45 45 45 45
  175   57 57 57 57 57 57 57 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 57 57 57 57 57 57 57 57
  180  125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125

                  GAIN DEGRADATION IS
                   -10.579
```

Figure 4.34
Pattern 4. 1 Percent Error
Maximum Impact on the Main Beam

```
         BORESIGHT AT 90,90

THETA                                PHI

         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0   124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124
   5    57 57 57 57 57 56 56 56 56 56 55 55 55 55 55 54 54 54 54 54 54 54 55 55 55 55 55 56 56 56 56 56 57 57 57 57 57
  10    46 46 46 46 46 47 47 47 47 47 46 46 45 44 44 43 43 42 42 42 43 43 44 44 45 46 46 47 47 47 47 47 46 46 46 46 46
  15    38 38 38 38 38 38 38 38 38 39 40 40 40 39 38 37 36 36 35 36 36 37 38 39 40 40 40 39 38 38 38 38 38 38 38 38 38
  20    35 35 35 34 34 34 34 33 33 33 34 34 35 36 35 34 32 31 31 31 32 34 35 36 35 34 34 33 33 33 34 34 34 34 35 35 35
  25    34 34 34 33 33 33 32 32 32 31 31 31 31 32 33 32 30 29 29 29 30 32 33 32 31 31 31 31 32 32 32 33 33 33 34 34 34
  30    48 47 44 40 37 35 33 32 31 31 31 31 30 30 31 31 30 29 28 29 30 31 31 30 30 31 31 31 31 32 33 35 37 40 44 47 48
  35    33 33 34 35 38 41 39 35 33 32 32 33 33 31 31 31 32 32 32 32 32 31 31 31 33 33 32 32 33 35 39 41 38 35 34 33 33
  40    34 34 34 34 34 34 35 34 33 32 32 35 37 34 31 32 35 42 47 42 35 32 31 34 37 35 32 32 33 34 35 34 34 34 34 34 34
  45    34 34 35 37 39 44 42 36 33 31 31 33 35 32 30 32 35 31 29 31 35 32 30 32 35 33 31 31 33 36 42 44 39 37 35 34 34
  50    32 32 32 33 34 36 39 45 40 35 34 34 35 33 32 33 32 28 26 28 32 33 32 33 35 34 34 35 40 45 39 36 34 33 32 32 32
  55    55 56 59 63 56 50 46 44 42 41 40 39 39 38 36 36 39 44 44 44 39 36 36 38 39 39 40 41 42 44 46 50 56 63 59 56 55
  60    33 33 32 32 30 30 29 31 35 53 32 27 24 22 21 22 24 21 19 21 24 22 21 22 24 27 32 53 35 31 29 30 30 32 32 33 33
  65    33 33 32 31 30 28 27 27 30 38 34 25 20 16 13 13 14 13 11 13 14 13 13 16 20 25 34 38 30 27 27 28 30 31 32 33 33
  70    36 36 35 34 33 33 34 35 37 42 41 29 20 13 10  8  8  8  8  8  8  8 10 13 20 29 41 42 37 35 34 33 33 34 35 36 36
  75    37 36 34 32 30 30 30 31 32 35 42 38 23 14  9  6  5  6  6  6  5  6  9 14 23 38 42 35 32 31 30 30 30 32 34 36 37
  80    44 42 39 35 32 30 29 28 28 29 35 45 27 15  9  5  4  4  3  4  4  5  9 15 27 45 35 29 28 28 29 30 32 35 39 42 44
  85    60 54 47 41 37 35 34 33 31 31 32 47 22 13  8  6  4  2  1  2  4  6  8 13 22 47 32 31 31 33 34 35 37 41 47 54 60
  90   138 62 50 43 39 38 39 40 35 32 32 45 20 12  7  6  4  1  0  1  4  6  7 12 20 45 32 32 35 40 39 38 39 43 50 62138
  95    60 54 47 41 37 35 34 33 31 31 32 47 22 13  8  6  4  2  1  2  4  6  8 13 22 47 32 31 31 33 34 35 37 41 47 54 60
 100    44 42 39 35 32 30 29 28 28 29 35 45 27 15  9  5  4  4  3  4  4  5  9 15 27 45 35 29 28 28 29 30 32 35 39 42 44
 105    37 36 34 32 30 30 30 31 32 35 42 38 23 14  9  6  5  6  6  6  5  6  9 14 23 38 42 35 32 31 30 30 30 32 34 36 37
 110    36 36 35 34 33 33 34 35 37 42 41 29 20 13 10  8  8  8  8  8  8  8 10 13 20 29 41 42 37 35 34 33 33 34 35 36 36
 115    33 33 32 31 30 28 27 27 30 38 34 25 20 16 13 13 14 13 11 13 14 13 13 16 20 25 34 38 30 27 27 28 30 31 32 33 33
 120    33 33 32 32 30 30 29 31 35 53 32 27 24 22 21 22 24 21 19 21 24 22 21 22 24 27 32 53 35 31 29 30 30 32 32 33 33
 125    55 56 59 63 56 50 46 44 42 41 40 39 39 38 36 36 39 44 44 44 39 36 36 38 39 39 40 41 42 44 46 50 56 63 59 56 55
 130    32 32 32 33 34 36 39 45 40 35 34 34 35 33 32 33 32 28 26 28 32 33 32 33 35 34 34 35 40 45 39 36 34 33 32 32 32
 135    34 34 35 37 39 44 42 36 33 31 31 33 35 32 30 32 35 31 29 31 35 32 30 32 35 33 31 31 33 36 42 44 39 37 35 34 34
 140    34 34 34 34 34 34 35 34 33 32 32 35 37 34 31 32 35 42 47 42 35 32 31 34 37 35 32 32 33 34 35 34 34 34 34 34 34
 145    33 33 34 35 38 41 39 35 33 32 32 33 33 31 31 31 32 32 32 32 32 31 31 31 33 33 32 32 33 35 39 41 38 35 34 33 33
 150    48 47 44 40 37 35 33 32 31 31 31 31 30 30 31 31 30 29 28 29 30 31 31 30 30 31 31 31 31 32 33 35 37 40 44 47 48
 155    34 34 34 33 33 33 32 32 32 31 31 31 31 32 33 32 30 29 29 29 30 32 33 32 31 31 31 31 32 32 32 33 33 33 34 34 34
 160    35 35 35 34 34 34 34 33 33 33 34 34 35 36 35 34 32 31 31 31 32 34 35 36 35 34 34 33 33 33 34 34 34 34 35 35 35
 165    38 38 38 38 38 38 38 38 38 39 40 40 40 39 38 37 36 36 35 36 36 37 38 39 40 40 40 39 38 38 38 38 38 38 38 38 38
 170    46 46 46 46 46 47 47 47 47 47 46 46 45 44 44 43 43 42 42 42 43 43 44 44 45 46 46 47 47 47 47 47 46 46 46 46 46
 175    57 57 57 57 57 56 56 56 56 56 55 55 55 55 55 54 54 54 54 54 54 54 55 55 55 55 55 56 56 56 56 56 57 57 57 57 57
 180   124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124

                    GAIN DEGRADATION IS
                     -10.504
```

Figure 4.35
Pattern 4. 2 Percent Error
Maximum Impact on the Main Beam

```
          BORESIGHT AT 90,90

THETA                            PHI

       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0  124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124
  5   56 56 56 56 56 56 56 55 55 55 55 55 54 54 54 54 54 53 53 53 54 54 54 54 54 55 55 55 55 55 56 56 56 56 56 56 56
 10   38 38 38 38 38 39 39 40 41 42 43 43 44 44 43 42 42 42 41 42 42 42 43 44 44 43 43 42 41 40 39 39 38 38 38 38 38
 15   28 28 28 28 28 28 29 29 30 30 31 33 34 36 37 37 36 35 35 35 36 37 37 36 34 33 31 30 30 29 29 28 28 28 28 28 28
 20   25 25 25 25 24 24 24 24 23 24 24 25 27 29 31 33 32 31 31 31 32 33 31 29 27 25 24 24 23 24 24 24 24 25 25 25 25
 25   27 27 27 26 25 24 23 22 21 21 21 21 22 23 26 29 31 29 28 29 31 29 26 23 22 21 21 21 21 22 23 24 25 26 27 27 27
 30   36 36 34 33 30 28 26 24 23 21 20 20 20 20 23 27 31 30 29 30 31 27 23 20 20 20 20 21 23 24 26 28 30 33 34 36 36
 35   39 39 42 48 50 38 32 29 26 24 22 21 20 20 22 25 32 38 34 38 32 25 22 20 20 21 22 24 26 29 32 38 50 48 42 39 39
 40   38 38 38 39 41 41 37 33 29 27 25 24 23 23 23 26 31 35 34 35 31 26 23 23 23 24 25 27 29 33 37 41 41 39 38 38 38
 45   37 37 39 45 54 41 35 31 29 28 27 28 28 27 27 28 29 27 26 27 29 28 27 27 28 28 27 28 29 31 35 41 54 45 39 37 37
 50   34 34 35 38 41 39 34 30 28 27 28 30 32 31 29 29 29 26 25 26 29 29 29 31 32 30 28 27 28 30 34 39 41 38 35 34 34
 55   43 44 49 53 41 35 31 29 28 28 29 30 30 30 29 31 36 44 37 44 36 31 29 30 30 30 29 28 28 29 31 35 41 53 49 44 43
 60   42 41 39 37 34 31 28 27 27 30 33 27 22 20 19 20 23 18 16 18 23 20 19 20 22 27 33 30 27 27 28 31 34 37 39 41 42
 65   38 37 36 35 33 31 29 27 28 31 39 26 19 14 12 12 12 10  9 10 12 12 12 14 19 26 39 31 28 27 29 31 33 35 36 37 38
 70   37 37 36 35 34 34 34 34 34 36 40 28 18 12  8  6  6  5  5  5  6  6  8 12 18 28 40 36 34 34 34 34 34 35 36 37 37
 75   38 37 35 33 32 33 37 45 34 32 34 32 21 12  6  4  3  3  3  3  3  4  6 12 21 32 34 32 34 45 37 33 32 33 35 37 38
 80   43 41 37 34 31 30 33 38 31 28 28 34 25 13  6  3  2  2  2  2  2  3  6 13 25 34 28 28 31 38 33 30 31 34 37 41 43
 85   55 49 41 35 32 30 32 44 32 26 26 30 20 10  5  3  2  1  0  1  2  3  5 10 20 30 26 26 32 44 32 30 32 35 41 49 55
 90  127 55 43 36 32 30 31 42 32 26 25 29 18  9  5  3  2  1  0  1  2  3  5  9 18 29 25 26 32 42 31 30 32 36 43 55127
 95   55 49 41 35 32 30 32 44 32 26 26 30 20 10  5  3  2  1  0  1  2  3  5 10 20 30 26 26 32 44 32 30 32 35 41 49 55
100   43 41 37 34 31 30 33 38 31 28 28 34 25 13  6  3  2  2  2  2  2  3  6 13 25 34 28 28 31 38 33 30 31 34 37 41 43
105   38 37 35 33 32 33 37 45 34 32 34 32 21 12  6  4  3  3  3  3  3  4  6 12 21 32 34 32 34 45 37 33 32 33 35 37 38
110   37 37 36 35 34 34 34 34 34 36 40 28 18 12  8  6  6  5  5  5  6  6  8 12 18 28 40 36 34 34 34 34 34 35 36 37 37
115   38 37 36 35 33 31 29 27 28 31 39 26 19 14 12 12 12 10  9 10 12 12 12 14 19 26 39 31 28 27 29 31 33 35 36 37 38
120   42 41 39 37 34 31 28 27 27 30 33 27 22 20 19 20 23 18 16 18 23 20 19 20 22 27 33 30 27 27 28 31 34 37 39 41 42
125   43 44 49 53 41 35 31 29 28 28 29 30 30 30 29 31 36 44 37 44 36 31 29 30 30 30 29 28 28 29 31 35 41 53 49 44 43
130   34 34 35 38 41 39 34 30 28 27 28 30 32 31 29 29 29 26 25 26 29 29 29 31 32 30 28 27 28 30 34 39 41 38 35 34 34
135   37 37 39 45 54 41 35 31 29 28 27 28 28 27 27 28 29 27 26 27 29 28 27 27 28 28 27 28 29 31 35 41 54 45 39 37 37
140   38 38 38 39 41 41 37 33 29 27 25 24 23 23 23 26 31 35 34 35 31 26 23 23 23 24 25 27 29 33 37 41 41 39 38 38 38
145   39 39 42 48 50 38 32 29 26 24 22 21 20 20 22 25 32 38 34 38 32 25 22 20 20 21 22 24 26 29 32 38 50 48 42 39 39
150   36 36 34 33 30 28 26 24 23 21 20 20 20 20 23 27 31 30 29 30 31 27 23 20 20 20 20 21 23 24 26 28 30 33 34 36 36
155   27 27 27 26 25 24 23 22 21 21 21 21 22 23 26 29 31 29 28 29 31 29 26 23 22 21 21 21 21 22 23 24 25 26 27 27 27
160   25 25 25 25 24 24 24 23 23 24 24 25 27 29 31 33 32 31 31 31 32 33 31 29 27 25 24 24 23 23 24 24 24 25 25 25 25
165   26 28 28 28 28 28 29 29 30 30 31 33 34 36 37 37 36 35 35 35 36 37 37 36 34 33 31 30 30 29 29 28 28 28 28 28 28
170   38 38 38 38 38 39 39 40 41 42 43 43 44 44 43 42 42 42 41 42 42 42 43 44 44 43 43 42 41 40 39 39 38 38 38 38 38
175   56 56 56 56 56 56 56 55 55 55 55 55 54 54 54 54 54 53 53 53 54 54 54 54 54 55 55 55 55 55 56 56 56 56 56 56 56
180  124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124124

                GAIN DEGRADATION IS
                 -10.583
```

Figure 4.36
Pattern 4. 1 Percent Error
Maximum Impact on Side Lobe 1

```
         BORESIGHT AT 90,90
THETA                          PHI
      0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

  0  122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122
  5   56 56 56 56 56 56 56 55 55 55 54 54 53 53 52 52 52 52 52 52 52 52 52 52 53 53 54 54 55 55 55 56 56 56 56 56 56 56
 10   34 34 34 34 35 35 36 37 38 39 41 43 44 44 43 41 41 40 40 40 41 41 43 44 44 43 41 39 38 37 36 35 35 34 34 34 34
 15   24 24 24 24 24 24 24 25 26 26 28 29 32 35 37 36 35 33 33 33 35 36 37 35 32 29 28 26 26 25 24 24 24 24 24 24 24
 20   21 21 21 21 20 20 20 20 20 20 20 21 23 25 29 33 32 30 29 30 32 33 29 25 23 21 20 20 20 20 20 20 20 21 21 21 21
 25   24 24 23 23 22 21 20 19 18 18 17 18 19 20 23 28 31 28 27 28 31 28 23 20 19 18 17 18 18 19 20 21 22 23 23 24 24
 30   31 31 30 29 27 25 23 21 20 18 17 16 16 17 20 23 31 29 27 29 31 23 20 17 16 16 17 18 20 21 23 25 27 29 30 31 31
 35   35 35 35 36 35 32 29 26 23 20 19 17 16 17 18 21 29 38 31 38 29 21 18 17 16 17 19 20 23 26 29 32 35 36 35 35 35
 40   36 36 37 38 39 38 33 29 26 23 21 20 19 19 20 21 26 31 31 31 26 21 20 19 19 20 21 23 26 29 33 38 39 38 37 36 36
 45   32 32 33 34 35 34 32 29 26 25 24 23 23 22 23 24 25 24 23 24 25 24 23 22 23 23 24 25 26 29 32 34 35 34 33 32 32
 50   33 33 33 34 34 33 30 27 25 24 24 25 27 28 28 27 25 23 22 23 25 27 28 28 27 25 24 24 25 27 30 33 34 34 33 33 33
 55   42 42 40 38 34 31 29 27 25 25 25 25 25 25 26 27 30 36 40 36 30 27 26 25 25 25 25 25 25 27 29 31 34 38 40 42 42
 60   37 36 35 33 30 28 26 25 25 26 27 24 20 18 18 20 24 20 17 20 24 20 18 18 20 24 27 26 25 25 26 28 30 33 35 36 37
 65   36 35 34 32 30 28 26 25 25 27 30 24 18 13 11 12 13 11  9 11 13 12 11 13 18 24 30 27 25 25 26 28 30 32 34 35 36
 70   36 35 34 33 32 31 30 29 28 28 30 25 18 12  8  6  6  6  5  6  6  6  8 12 18 25 30 28 28 29 30 31 32 33 34 35 36
 75   36 36 34 32 31 31 35 35 28 26 27 27 21 12  6  3  3  3  3  3  3  3  6 12 21 27 27 26 28 35 35 31 31 32 34 36 36
 80   41 39 36 32 30 29 32 40 28 24 24 27 28 13  6  3  1  2  2  2  1  3  6 13 28 27 24 24 28 40 32 29 30 32 36 39 41
 85   53 47 39 34 30 29 31 37 28 23 22 27 21 11  5  3  2  1  1  1  2  3  5 11 20 27 22 23 28 37 31 29 30 34 39 47 53
 90  126 53 42 35 31 29 30 34 27 22 21 27 19 10  5  3  2  1  0  1  2  3  5 10 19 27 21 22 27 34 30 29 31 35 42 53126
 95   53 47 39 34 30 29 31 37 28 23 22 27 21 11  5  3  2  1  1  1  2  3  5 11 20 27 22 23 28 37 31 29 30 34 39 47 53
100   41 39 36 32 30 29 32 40 28 24 24 27 28 13  6  3  1  2  2  2  1  3  6 13 28 27 24 24 28 40 32 29 30 32 36 39 41
105   36 36 34 32 31 31 35 35 28 26 27 27 21 12  6  3  3  3  3  3  3  3  6 12 21 27 27 26 28 35 35 31 31 32 34 36 36
110   36 35 34 33 32 31 30 29 28 28 30 25 18 12  8  6  6  6  5  6  6  6  8 12 18 25 30 28 28 29 30 31 32 33 34 35 36
115   36 35 34 32 30 28 26 25 25 27 30 24 18 13 11 12 13 11  9 11 13 12 11 13 18 24 30 27 25 25 26 28 30 32 34 35 36
120   37 36 35 33 30 28 26 25 25 26 27 24 20 18 18 20 24 20 17 20 24 20 18 18 20 24 27 26 25 25 26 28 30 33 35 36 37
125   42 42 40 38 34 31 29 27 25 25 25 25 25 25 26 27 30 36 40 36 30 27 26 25 25 25 25 25 25 27 29 31 34 38 40 42 42
130   33 33 33 34 34 33 30 27 25 24 24 25 27 28 28 27 25 23 22 23 25 27 28 28 27 25 24 24 25 27 30 33 34 34 33 33 33
135   32 32 33 34 35 34 32 29 26 25 24 23 23 22 23 24 25 24 23 24 25 24 23 22 23 23 24 25 26 29 32 34 35 34 33 32 32
140   36 36 37 38 39 38 33 29 26 23 21 20 19 19 20 21 26 31 31 31 26 21 20 19 19 20 21 23 26 29 33 38 39 38 37 36 36
145   35 35 35 36 35 32 29 26 23 20 19 17 16 17 18 21 29 38 31 38 29 21 18 17 16 17 19 20 23 26 29 32 35 36 35 35 35
150   31 31 30 29 27 25 23 21 20 18 17 16 16 17 20 23 31 29 27 29 31 23 20 17 16 16 17 18 20 21 23 25 27 29 30 31 31
155   24 24 23 23 22 21 20 19 18 18 17 18 19 20 23 28 31 28 27 28 31 28 23 20 19 18 17 18 18 19 20 21 22 23 23 24 24
160   21 21 21 21 20 20 20 20 20 20 20 21 23 25 29 33 32 30 29 30 32 33 29 25 23 21 20 20 20 20 20 20 20 21 21 21 21
165   24 24 24 24 24 24 24 25 26 26 28 29 32 35 37 36 35 33 33 33 35 36 37 35 32 29 28 26 26 25 24 24 24 24 24 24 24
170   34 34 34 34 35 35 36 37 38 39 41 43 44 44 43 41 41 40 40 40 41 41 43 44 44 43 41 39 38 37 36 35 35 34 34 34 34
175   56 56 56 56 56 56 56 55 55 55 54 54 53 53 52 52 52 52 52 52 52 52 52 52 53 53 54 54 55 55 55 56 56 56 56 56 56 56
180  122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122

                GAIN DEGRADATION IS
                  -10.505
```

Figure 4.37
Pattern 4. 2 Percent Error
Maximum Impact on Side Lobe 1

```
          BORESIGHT AT 90,90
THETA                                        PHI
        0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0   126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126
   5    57 57 57 57 57 57 57 57 57 57 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 57 57 57 57 57 57 57 57 57 57
  10    45 45 45 45 45 46 46 46 46 46 46 45 45 45 45 44 44 44 44 44 44 44 45 45 45 45 46 46 46 46 46 46 45 45 45 45 45
  15    36 36 36 36 36 37 37 37 38 38 39 39 39 39 38 38 38 37 37 37 38 38 38 39 39 39 39 38 38 37 37 37 36 36 36 36 36
  20    32 32 31 31 31 31 31 31 32 32 33 33 34 35 35 34 34 33 33 33 34 34 35 35 34 33 33 32 32 31 31 31 31 31 31 32 32
  25    33 33 32 31 31 30 29 29 29 29 29 29 30 31 32 32 32 31 31 31 32 32 32 31 30 29 29 29 29 29 29 30 31 31 32 33 33
  30    36 36 36 36 35 33 31 30 29 28 28 28 28 29 30 32 32 32 32 32 32 32 30 29 28 28 28 28 29 30 31 33 35 36 36 36 36
  35    29 29 30 31 32 33 34 33 31 30 29 29 29 29 30 32 36 39 39 39 36 32 30 29 29 29 29 30 31 33 34 33 32 31 30 29 29
  40    31 31 31 30 30 30 31 31 31 31 32 33 32 31 30 32 38 38 36 38 38 32 30 31 32 33 32 31 31 31 31 30 30 30 31 31 31
  45    38 39 40 40 38 34 32 30 30 31 33 36 34 30 29 30 32 30 28 30 32 30 29 30 34 36 33 31 30 30 32 34 38 40 40 39 38
  50    31 31 33 36 42 44 35 31 30 31 35 41 35 30 28 29 30 29 29 29 30 29 28 30 35 41 35 31 30 31 35 44 42 36 33 31 31
  55    32 32 33 34 36 35 33 31 31 34 45 43 40 49 37 34 34 29 27 29 34 34 37 49 40 43 45 34 31 31 33 35 36 34 33 32 32
  60    31 30 30 30 29 28 27 27 29 33 37 31 26 21 20 21 22 17 15 17 22 21 20 21 26 31 37 33 29 27 27 28 29 30 30 30 31
  65    31 31 30 29 28 27 27 27 28 30 31 29 20 15 12 11 12 10  9 10 12 11 12 15 20 29 31 30 28 27 27 27 28 29 30 31 31
  70    36 36 35 34 33 33 34 35 34 31 29 30 20 12  8  6  6  5  5  5  6  6  8 12 20 30 29 31 34 35 34 33 33 34 35 36 36
  75    36 35 33 31 29 27 26 25 25 26 30 32 21 12  6  3  2  3  3  3  2  3  6 12 21 32 30 26 25 25 26 27 29 31 33 35 36
  80    38 36 32 28 25 23 22 22 21 23 28 30 20 12  6  3  2  2  2  2  2  3  6 12 20 30 28 23 21 22 22 23 25 28 32 36 38
  85    47 42 34 28 24 21 20 21 22 23 27 27 16  9  5  3  2  1  1  1  2  3  5  9 16 27 27 23 22 21 20 21 24 28 34 42 47
  90   117 47 35 28 23 21 20 21 23 24 27 26 15  8  4  3  2  1  0  1  2  3  4  8 15 26 27 24 23 21 20 21 23 28 35 47117
  95    47 42 34 28 24 21 20 21 22 23 27 27 16  9  5  3  2  1  1  1  2  3  5  9 16 27 27 23 22 21 20 21 24 28 34 42 47
 100    38 36 32 28 25 23 22 22 21 23 28 30 20 12  6  3  2  2  2  2  2  3  6 12 20 30 28 23 21 22 22 23 25 28 32 36 38
 105    36 35 33 31 29 27 26 25 25 26 30 32 21 12  6  3  2  3  3  3  2  3  6 12 21 32 30 26 25 25 26 27 29 31 33 35 36
 110    36 36 35 34 33 33 34 35 34 31 29 30 20 12  8  6  6  5  5  5  6  6  8 12 20 30 29 31 34 35 34 33 33 34 35 36 36
 115    31 31 30 29 28 27 27 27 28 30 31 29 20 15 12 11 12 10  9 10 12 11 12 15 20 29 31 30 28 27 27 27 28 29 30 31 31
 120    31 30 30 30 29 28 27 27 29 33 37 31 26 21 20 21 22 17 15 17 22 21 20 21 26 31 37 33 29 27 27 28 29 30 30 30 31
 125    32 32 33 34 36 35 33 31 31 34 45 43 40 49 37 34 34 29 27 29 34 34 37 49 40 43 45 34 31 31 33 35 36 34 33 32 32
 130    31 31 33 36 42 44 35 31 30 31 35 41 35 30 28 29 30 29 29 29 30 29 28 30 35 41 35 31 30 31 35 44 42 36 33 31 31
 135    38 39 40 40 38 34 32 30 30 31 33 36 34 30 29 30 32 30 28 30 32 30 29 30 34 36 33 31 30 30 32 34 38 40 40 39 38
 140    31 31 31 30 30 30 31 31 31 31 32 33 32 31 30 32 38 38 36 38 38 32 30 31 32 33 32 31 31 31 31 30 30 30 31 31 31
 145    29 29 30 31 32 33 34 33 31 30 29 29 29 29 30 32 36 39 39 39 36 32 30 29 29 29 29 30 31 33 34 33 32 31 30 29 29
 150    36 36 36 36 35 33 31 30 29 28 28 28 28 29 30 32 32 32 32 32 32 32 30 29 28 28 28 28 29 30 31 33 35 36 36 36 36
 155    33 33 32 31 31 30 29 29 29 29 29 29 30 31 32 32 32 31 31 31 32 32 32 31 30 29 29 29 29 29 29 30 31 31 32 33 33
 160    32 32 31 31 31 31 31 31 32 32 33 33 34 35 35 34 34 33 33 33 34 34 35 35 34 33 33 32 32 31 31 31 31 31 31 32 32
 165    36 36 36 36 36 37 37 37 38 38 39 39 39 39 38 38 38 37 37 37 38 38 38 39 39 39 39 38 38 37 37 37 36 36 36 36 36
 170    45 45 45 45 45 46 46 46 46 46 46 45 45 45 45 44 44 44 44 44 44 44 45 45 45 45 46 46 46 46 46 46 45 45 45 45 45
 175    57 57 57 57 57 57 57 57 57 57 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 57 57 57 57 57 57 57 57 57 57
 180   126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126126

                  GAIN DEGRADATION IS
                   -10.681
```

Figure 4.38
Pattern 4. 1 Percent Error
Maximum Impact on Side Lobe 2

```
        BORESIGHT AT 90,90

THETA                              PHI

         0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0    127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127
   5     56 56 56 56 56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56 56 56 56 56
  10     45 45 45 45 45 45 45 45 45 45 45 45 44 44 44 44 43 43 43 43 43 44 44 44 44 45 45 45 45 45 45 45 45 45 45 45 45
  15     35 35 35 35 36 36 36 37 37 38 38 38 38 38 38 37 37 37 37 37 37 37 38 38 38 38 38 38 37 37 36 36 36 35 35 35 35
  20     30 30 30 30 30 30 30 30 31 31 32 33 34 34 34 34 33 33 32 33 33 34 34 34 34 33 32 31 31 30 30 30 30 30 30 30 30
  25     31 31 30 30 29 28 28 27 27 27 28 29 30 31 32 32 31 31 31 31 31 32 32 31 30 29 28 27 27 27 28 28 29 30 30 31 31
  30     31 31 31 31 31 31 30 28 27 26 26 27 28 29 31 32 32 32 32 32 32 32 31 29 28 27 26 26 27 28 30 31 31 31 31 31 31
  35     26 26 26 27 27 28 29 30 29 28 27 28 29 29 31 33 37 43 46 43 37 33 31 29 29 28 27 28 29 30 29 28 27 27 26 26 26
  40     27 27 27 27 26 26 27 28 29 29 30 32 33 32 31 33 36 34 32 34 36 33 31 32 33 32 30 29 29 28 27 26 26 27 27 27 27
  45     36 36 36 34 31 29 27 26 27 29 32 38 36 31 29 30 31 28 27 28 31 30 29 31 36 38 32 29 27 26 27 29 31 34 36 36 36
  50     28 28 30 32 36 34 30 27 27 29 35 45 34 30 27 27 28 29 29 29 28 27 27 30 34 45 35 29 27 27 30 34 36 32 30 28 28
  55     28 28 28 29 30 30 29 28 29 33 51 34 32 41 36 31 29 26 25 26 29 31 36 41 32 34 51 33 29 28 29 30 30 29 28 28 28
  60     26 26 26 25 25 24 24 25 27 31 30 27 24 20 19 20 22 17 15 17 22 20 19 20 24 27 30 31 27 25 24 24 25 25 26 26 26
  65     27 26 26 25 24 24 24 25 26 27 26 25 19 14 11 11 11  9  8  9 11 11 11 14 19 25 26 27 26 25 24 24 24 25 26 26 27
  70     35 34 33 32 31 31 32 31 29 26 24 26 19 11  7  5  4  4  4  4  4  5  7 11 19 26 24 26 29 31 32 31 31 32 33 34 35
  75     33 32 30 27 25 23 22 21 21 22 24 26 20 11  5  2  1  2  2  2  1  2  5 11 20 26 24 22 21 21 22 23 25 27 30 32 33
  80     34 32 28 24 21 19 18 17 18 19 22 24 18 10  5  2  0  1  1  1  0  2  5 10 18 24 22 19 18 17 18 19 21 24 28 32 34
  85     43 37 29 23 19 17 16 16 17 18 20 21 14  7  3  1  1  0  0  0  1  1  3  7 14 21 20 18 17 16 16 17 19 23 29 37 43
  90    112 42 30 23 19 17 15 16 17 18 19 20 12  6  3  1  1  0  0  0  1  1  3  6 12 20 19 18 17 16 15 17 19 23 30 42112
  95     43 37 29 23 19 17 16 16 17 18 20 21 14  7  3  1  1  0  0  0  1  1  3  7 14 21 20 18 17 16 16 17 19 23 29 37 43
 100     34 32 28 24 21 19 18 17 18 19 22 24 18 10  5  2  0  1  1  1  0  2  5 10 18 24 22 19 18 17 18 19 21 24 28 32 34
 105     33 32 30 27 25 23 22 21 21 22 24 26 20 11  5  2  1  2  2  2  1  2  5 11 20 26 24 22 21 21 22 23 25 27 30 32 33
 110     35 34 33 32 31 31 32 31 29 26 24 26 19 11  7  5  4  4  4  4  4  5  7 11 19 26 24 26 29 31 32 31 31 32 33 34 35
 115     27 26 26 25 24 24 24 25 26 27 26 25 19 14 11 11 11  9  8  9 11 11 11 14 19 25 26 27 26 25 24 24 24 25 26 26 27
 120     26 26 26 25 25 24 24 25 27 31 30 27 24 20 19 20 22 17 15 17 22 20 19 20 24 27 30 31 27 25 24 24 25 25 26 26 26
 125     28 28 28 29 30 30 29 28 29 33 51 34 32 41 36 31 29 26 25 26 29 31 36 41 32 34 51 33 29 28 29 30 30 29 28 28 28
 130     28 28 30 32 36 34 30 27 27 29 35 45 34 30 27 27 28 29 29 29 28 27 27 30 34 45 35 29 27 27 30 34 36 32 30 28 28
 135     36 36 36 34 31 29 27 26 27 29 32 38 36 31 29 30 31 28 27 28 31 30 29 31 36 38 32 29 27 26 27 29 31 34 36 36 36
 140     27 27 27 27 26 26 27 28 29 29 30 32 33 32 31 33 36 34 32 34 36 33 31 32 33 32 30 29 29 28 27 26 26 27 27 27 27
 145     26 26 26 27 27 28 29 30 29 28 27 28 29 29 31 33 37 43 46 43 37 33 31 29 29 28 27 28 29 30 29 28 27 27 26 26 26
 150     31 31 31 31 31 31 30 28 27 26 26 27 28 29 31 32 32 32 32 32 32 32 31 29 28 27 26 26 27 28 30 31 31 31 31 31 31
 155     31 31 30 30 29 28 28 27 27 27 28 29 30 31 32 32 31 31 31 31 31 32 32 31 30 29 28 27 27 27 28 28 29 30 30 31 31
 160     30 30 30 30 30 30 30 30 31 31 32 33 34 34 34 34 33 33 32 33 33 34 34 34 34 33 32 31 31 30 30 30 30 30 30 30 30
 165     35 35 35 35 36 36 36 37 37 38 38 38 38 38 38 37 37 37 37 37 37 37 38 38 38 38 38 38 37 37 36 36 36 35 35 35 35
 170     45 45 45 45 45 45 45 45 45 45 45 45 44 44 44 44 43 43 43 43 43 44 44 44 44 45 45 45 45 45 45 45 45 45 45 45 45
 175     56 56 56 56 56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56 56 56 56 56
 180    127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127127

                GAIN DEGRADATION IS
                 -10.706
```

Figure 4.39
Pattern 4. 2 Percent Error
Maximum Impact on Side Lobe 2

```
          BORESIGHT AT 90,90

THETA                               PHI

       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0 125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125
   5  56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56
  10  45 45 45 45 44 44 44 44 44 44 44 44 44 43 43 43 43 43 43 43 43 43 43 43 44 44 44 44 44 44 44 44 44 45 45 45 45
  15  39 39 39 38 38 38 38 38 38 38 37 37 37 37 37 36 36 36 36 36 36 36 37 37 37 37 37 38 38 38 38 38 38 38 39 39 39
  20  38 38 37 37 36 36 35 34 34 33 33 32 32 32 32 32 31 31 31 31 31 32 32 32 32 32 33 33 34 34 35 36 36 37 37 38 38
  25  41 41 40 40 39 37 36 34 33 31 30 29 28 28 28 28 28 27 27 27 28 28 28 28 28 29 30 31 33 34 36 37 39 40 40 41 41
  30  37 37 37 37 37 37 36 35 33 31 29 27 26 25 25 25 25 25 25 25 25 25 25 25 26 27 29 31 33 35 36 37 37 37 37 37 37
  35  39 39 39 38 37 36 35 34 33 31 29 27 25 24 23 23 24 25 25 25 24 23 23 24 25 27 29 31 33 34 35 36 37 38 39 39 39
  40  39 40 42 45 47 45 41 37 33 31 29 27 26 25 25 24 25 25 26 25 25 24 25 25 26 27 29 31 33 37 41 45 47 45 42 40 39
  45  30 31 31 31 32 32 33 37 38 32 29 30 33 26 21 19 17 17 17 17 17 19 21 26 33 30 29 32 38 37 33 32 32 31 31 31 30
  50  29 30 30 31 30 28 27 29 36 36 29 31 31 19 13 11  9  9  9  9  9 11 13 19 31 31 29 36 36 29 27 28 30 31 30 30 29
  55  27 27 29 32 34 31 27 26 30 43 27 28 27 14  9  6  5  5  5  5  5  6  9 14 27 28 27 43 30 26 27 31 34 32 29 27 27
  60  26 26 27 29 33 41 31 28 29 42 27 26 28 13  7  4  3  3  3  3  3  4  7 13 28 26 27 42 29 28 31 41 33 29 27 26 26
  65  30 30 30 31 33 38 44 35 34 46 30 28 28 15  8  5  3  3  3  3  3  5  8 15 28 28 30 46 34 35 44 38 33 31 30 30 30
  70  35 35 34 33 33 35 41 45 37 38 38 40 26 15  9  5  3  3  3  3  3  5  9 15 26 40 38 39 37 45 41 35 33 33 34 35 35
  75  36 35 33 31 30 31 35 39 32 32 59 32 26 15  7  4  2  2  2  2  2  4  7 15 26 32 59 32 32 39 35 31 30 31 33 35 36
  80  44 42 38 34 32 31 33 39 34 33 49 36 28 14  7  3  2  2  2  2  2  3  7 14 28 36 49 33 34 39 33 31 32 34 38 42 44
  85  60 54 46 40 36 34 34 36 38 38 40 36 22 13  7  4  2  1  1  1  2  4  7 13 22 36 40 38 38 36 34 34 36 40 46 54 60
  90 136 63 51 44 40 37 36 35 35 35 36 30 20 13  7  4  2  0  0  0  2  4  7 13 20 30 36 35 35 35 36 37 40 44 51 63136
  95  60 54 46 40 36 34 34 36 38 38 40 36 22 13  7  4  2  1  1  1  2  4  7 13 22 36 40 38 38 36 34 34 36 40 46 54 60
 100  44 42 38 34 32 31 33 39 34 33 49 36 28 14  7  3  2  2  2  2  2  3  7 14 28 36 49 33 34 39 33 31 32 34 38 42 44
 105  36 35 33 31 30 31 35 39 32 32 59 32 26 15  7  4  2  2  2  2  2  4  7 15 26 32 59 32 32 39 35 31 30 31 33 35 36
 110  35 35 34 33 33 35 41 45 37 38 38 40 26 15  9  5  3  3  3  3  3  5  9 15 26 40 38 38 37 45 41 35 33 33 34 35 35
 115  30 30 30 31 33 38 44 35 34 46 30 28 28 15  8  5  3  3  3  3  3  5  8 15 28 28 30 46 34 35 44 38 33 31 30 30 30
 120  26 26 27 29 33 41 31 28 29 42 27 26 28 13  7  4  3  3  3  3  3  4  7 13 28 26 27 42 29 28 31 41 33 29 27 26 26
 125  27 27 29 32 34 31 27 26 30 43 27 28 27 14  9  6  5  5  5  5  5  6  9 14 27 28 27 43 30 26 27 31 34 32 29 27 27
 130  29 30 30 31 30 28 27 29 36 36 29 31 31 19 13 11  9  9  9  9  9 11 13 19 31 31 29 36 36 29 27 28 30 31 30 30 29
 135  30 31 31 31 32 32 33 37 38 32 29 30 33 26 21 19 17 17 17 17 17 19 21 26 33 30 29 32 38 37 33 32 32 31 31 31 30
 140  39 40 42 45 47 45 41 37 33 31 29 27 26 25 25 24 25 25 26 25 25 24 25 25 26 27 29 31 33 37 41 45 47 45 42 40 39
 145  39 39 39 38 37 36 35 34 33 31 29 27 25 24 23 23 24 25 25 25 24 23 23 24 25 27 29 31 33 34 35 36 37 38 39 39 39
 150  37 37 37 37 37 37 36 35 33 31 29 27 26 25 25 25 25 25 25 25 25 25 25 25 26 27 29 31 33 35 36 37 37 37 37 37 37
 155  41 41 40 40 39 37 36 34 33 31 30 29 28 28 28 28 28 27 27 27 28 28 28 28 28 29 30 31 33 34 36 37 39 40 40 41 41
 160  38 38 37 37 36 36 35 34 34 33 33 32 32 32 32 32 31 31 31 31 31 32 32 32 32 32 33 33 34 34 35 36 36 37 37 38 38
 165  39 39 39 38 38 38 38 38 38 38 37 37 37 37 37 36 36 36 36 36 36 36 37 37 37 37 37 38 38 38 38 38 38 38 39 39 39
 170  45 45 45 45 44 44 44 44 44 44 44 44 44 43 43 43 43 43 43 43 43 43 43 43 44 44 44 44 44 44 44 44 44 45 45 45 45
 175  56 56 56 56 56 56 56 56 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 56 56 56 56 56 56 56 56
 180 125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125125

              GAIN DEGRADATION IS
                -8.519
```

Figure 4.40
Pattern 5. 1 Percent Error
Maximum Impact on the Main Beam

```
            BORESIGHT AT 90,90
THETA                                    PHI
          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0     122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122
   5      52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52
  10      41 41 41 41 41 41 41 41 41 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 41 41 41 41 41 41 41 41 41
  15      35 35 35 35 34 34 34 34 34 34 34 34 33 33 33 33 33 33 33 33 33 33 33 33 33 34 34 34 34 34 34 34 34 35 35 35 35
  20      34 34 33 33 32 32 31 31 30 29 29 29 29 28 28 28 28 28 28 28 29 28 28 29 29 29 29 29 30 31 31 32 32 33 33 34 34
  25      37 37 36 36 35 33 32 30 29 28 26 26 25 25 25 25 25 25 25 25 25 25 25 25 25 26 26 28 29 30 32 33 35 36 36 37 37
  30      37 37 37 37 36 35 34 32 30 28 26 24 23 22 22 22 22 22 22 22 22 22 22 22 23 24 26 28 30 32 34 35 36 37 37 37 37
  35      40 40 40 39 39 37 35 33 31 28 26 24 22 22 21 21 22 22 22 22 22 21 21 22 22 24 26 28 31 33 35 37 39 39 40 40 40
  40      38 38 40 43 48 49 42 37 33 30 27 25 23 22 22 22 22 22 22 22 22 22 22 22 23 25 27 30 33 37 42 49 48 43 40 38 38
  45      30 30 31 31 32 33 34 37 38 32 29 28 27 25 22 19 18 17 17 17 18 19 22 25 27 28 29 32 38 37 34 33 32 31 31 30 30
  50      29 30 30 30 30 28 28 30 37 36 29 30 32 21 15 12 11 10 10 10 11 12 15 21 32 30 29 36 37 30 28 28 30 30 30 30 29
  55      28 29 30 33 34 30 27 27 31 42 27 28 30 16 10  7  6  6  6  6  6  7 10 16 33 28 27 42 31 27 27 30 34 33 30 29 28
  60      28 28 29 31 37 40 31 28 29 41 27 26 32 15  8  5  4  4  4  4  4  5  8 15 32 26 27 41 29 28 31 40 37 31 29 28 28
  65      33 33 33 34 36 43 40 34 34 48 30 28 32 16  9  6  4  4  4  4  4  6  9 16 32 28 30 48 34 34 40 43 36 34 33 33 33
  70      35 34 33 33 32 34 39 53 38 38 40 42 28 16 10  6  5  4  4  4  5  6 10 16 28 42 40 38 38 53 39 34 32 33 33 34 35
  75      35 34 32 30 29 29 32 39 33 31 43 33 27 16  9  5  4  3  4  3  4  5  9 16 27 33 43 31 33 39 32 29 29 30 32 34 35
  80      42 41 37 33 30 29 30 35 37 34 41 38 28 15  8  4  3  3  3  3  3  4  8 15 28 38 41 34 37 35 30 29 30 33 37 41 42
  85      59 53 45 39 35 33 32 34 39 51 51 33 22 14  8  5  3  2  1  2  3  5  8 14 22 33 51 51 39 34 32 33 35 39 45 53 59
  90     130 62 50 43 39 36 34 34 34 37 53 29 20 13  8  5  2  1  0  1  2  5  8 13 20 29 53 37 34 34 34 36 39 43 50 62130
  95      59 53 45 39 35 33 32 34 39 51 51 33 22 14  8  5  3  2  1  2  3  5  8 14 22 33 51 51 39 34 32 33 35 39 45 53 59
 100      42 41 37 33 30 29 30 35 37 34 41 38 28 15  8  4  3  3  3  3  3  4  8 15 28 38 41 34 37 35 30 29 30 33 37 41 42
 105      35 34 32 30 29 29 32 39 33 31 43 33 27 16  9  5  4  3  4  3  4  5  9 16 27 33 43 31 33 39 32 29 29 30 32 34 35
 110      35 34 33 33 32 34 39 53 38 38 40 42 28 16 10  6  5  4  4  4  5  6 10 16 28 42 40 38 38 53 39 34 32 33 33 34 35
 115      33 33 33 34 36 43 40 34 34 48 30 28 32 16  9  6  4  4  4  4  4  6  9 16 32 28 30 48 34 34 40 43 36 34 33 33 33
 120      28 28 29 31 37 40 31 28 29 41 27 26 32 15  8  5  4  4  4  4  4  5  8 15 32 26 27 41 29 28 31 40 37 31 29 28 28
 125      28 29 30 33 34 30 27 27 31 42 27 28 30 16 10  7  6  6  6  6  6  7 10 16 30 28 27 42 31 27 27 30 34 33 30 29 28
 130      29 30 30 30 30 28 28 30 37 36 29 30 32 21 15 12 11 10 10 10 11 12 15 21 32 30 29 36 37 30 28 28 30 30 30 30 29
 135      30 30 31 31 32 33 34 37 38 32 29 28 27 25 22 19 18 17 17 17 18 19 22 25 27 28 29 32 38 37 34 33 32 31 31 30 30
 140      38 38 40 43 48 49 42 37 33 30 27 25 23 22 22 22 22 22 22 22 22 22 22 22 23 25 27 30 33 37 42 49 48 43 40 38 38
 145      40 40 40 39 39 37 35 33 31 28 26 24 22 22 21 21 22 22 22 22 22 21 21 22 22 24 26 28 31 33 35 37 39 39 40 40 40
 150      37 37 37 37 36 35 34 32 30 28 26 24 23 22 22 22 22 22 22 22 22 22 22 22 23 24 26 28 30 32 34 35 36 37 37 37 37
 155      37 37 36 36 35 33 32 30 29 28 26 26 25 25 25 25 25 25 25 25 25 25 25 25 25 26 26 28 29 30 32 33 35 36 36 37 37
 160      34 34 33 33 32 32 31 31 30 29 29 29 29 28 28 28 28 28 28 28 28 28 28 28 29 29 29 29 30 31 31 32 32 33 33 34 34
 165      35 35 35 35 34 34 34 34 34 34 34 34 33 33 33 33 33 33 33 33 33 33 33 33 33 34 34 34 34 34 34 34 34 35 35 35 35
 170      41 41 41 41 41 41 41 41 41 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 41 41 41 41 41 41 41 41 41
 175      52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52 52
 180     122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122122

                   GAIN DEGRADATION IS
                     -8.581
```

Figure 4.41
Pattern 5. 2 Percent Error
Maximum Impact on the Main Beam

```
          BORESIGHT AT 90,90

THETA                                 PHI

          0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0   117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117
    5    47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 46 46 46 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47
   10    37 37 37 37 37 37 36 36 36 36 36 35 35 35 35 35 35 35 34 35 35 35 35 35 35 35 36 36 36 36 36 37 37 37 37 37 37
   15    34 34 34 34 33 33 32 32 31 30 30 29 29 29 28 28 28 28 28 28 28 28 28 29 29 29 30 30 31 32 32 33 33 34 34 34 34
   20    38 38 38 37 35 34 33 31 30 28 27 26 25 24 24 23 23 23 23 23 23 23 24 24 25 26 27 28 30 31 33 34 35 37 38 38 38
   25    50 50 49 47 44 41 38 34 31 28 26 24 23 22 21 20 20 20 20 20 20 20 21 22 23 24 25 28 31 34 38 41 44 47 49 50 50
   30    41 41 42 44 47 49 46 40 35 30 27 24 22 20 20 20 19 19 19 19 19 20 20 20 22 24 27 30 35 40 46 49 47 44 42 41 41
   35    36 37 37 37 38 39 39 38 36 32 28 25 22 20 20 20 19 19 19 19 19 20 20 20 22 25 28 32 36 38 39 39 38 37 37 37 36
   40    40 41 43 44 44 43 42 39 35 31 28 26 24 23 22 22 24 26 26 26 24 22 22 23 24 26 28 31 35 39 42 43 44 44 43 41 40
   45    29 29 29 29 29 29 30 33 39 33 28 28 29 24 20 18 17 17 17 17 17 18 20 24 29 28 28 33 39 33 30 29 29 29 29 29 29
   50    27 28 29 29 28 26 24 25 30 42 29 30 28 17 12  9  8  8  8  8  8  9 12 17 28 30 29 42 30 25 24 26 28 29 29 28 27
   55    24 24 25 28 33 30 25 24 26 41 28 29 25 13  7  5  3  3  3  3  3  5  7 13 25 29 28 41 26 24 25 30 33 28 25 24 24
   60    23 23 24 25 29 39 32 27 27 36 28 26 26 12  6  3  2  2  2  2  2  3  6 12 26 26 28 36 27 27 32 39 29 25 24 23 23
   65    28 28 27 28 29 34 58 35 33 44 30 28 28 14  7  4  2  2  2  2  2  4  7 14 28 28 30 44 33 35 58 34 29 28 27 28 28
   70    33 33 32 31 31 33 39 38 33 37 40 34 27 14  8  4  2  2  2  2  2  4  8 14 27 34 40 37 33 38 39 33 31 31 32 33 33
   75    37 37 35 33 32 33 38 36 30 32 42 29 27 14  6  2  1  1  1  1  1  2  6 14 27 29 42 32 30 36 38 33 32 33 35 37 37
   80    45 43 39 36 34 34 40 42 31 31 43 32 29 14  6  2  1  1  1  1  1  2  6 14 29 32 43 31 31 42 40 34 34 36 39 43 45
   85    55 49 41 36 32 31 32 40 37 31 31 35 24 13  6  3  1  1  1  1  1  3  6 13 24 35 31 31 37 40 32 31 32 36 41 49 55
   90   128 54 42 35 31 29 29 35 40 29 28 29 21 13  6  3  1  0  0  0  1  3  6 13 21 29 28 29 40 35 29 29 31 35 42 54128
   95    55 49 41 36 32 31 32 40 37 31 31 35 24 13  6  3  1  1  1  1  1  3  6 13 24 35 31 31 37 40 32 31 32 36 41 49 55
  100    45 43 39 36 34 34 40 42 31 31 43 32 29 14  6  2  1  1  1  1  1  2  6 14 29 32 43 31 31 42 40 34 34 36 39 43 45
  105    37 37 35 33 32 33 38 36 30 32 42 29 27 14  6  2  1  1  1  1  1  2  6 14 27 29 42 32 30 36 38 33 32 33 35 37 37
  110    33 33 32 31 31 33 39 38 33 37 40 34 27 14  8  4  2  2  2  2  2  4  8 14 27 34 40 37 33 38 39 33 31 31 32 33 33
  115    28 28 27 28 29 34 58 35 33 44 30 28 28 14  7  4  2  2  2  2  2  4  7 14 28 28 30 44 33 35 58 34 29 28 27 28 28
  120    23 23 24 25 29 39 32 27 27 36 28 26 26 12  6  3  2  2  2  2  2  3  6 12 26 26 28 36 27 27 32 39 29 25 24 23 23
  125    24 24 25 28 33 30 25 24 26 41 28 29 25 13  7  5  3  3  3  3  3  5  7 13 25 29 28 41 26 24 25 30 33 28 25 24 24
  130    27 28 29 29 28 26 24 25 30 42 29 30 28 17 12  9  8  8  8  8  8  9 12 17 28 30 29 42 30 25 24 26 28 29 29 28 27
  135    29 29 29 29 29 29 30 33 39 33 28 28 29 24 20 18 17 17 17 17 17 18 20 24 29 28 28 33 39 33 30 29 29 29 29 29 29
  140    40 41 43 44 44 43 42 39 35 31 28 26 24 23 22 22 24 26 26 26 24 22 22 23 24 26 28 31 35 39 42 43 44 44 43 41 40
  145    36 37 37 37 38 39 39 38 36 32 28 25 22 20 20 20 19 19 19 19 19 20 20 20 22 25 28 32 36 38 39 39 38 37 37 37 36
  150    41 41 42 44 47 49 46 40 35 30 27 24 22 20 20 20 19 19 19 19 19 20 20 20 22 24 27 30 35 40 46 49 47 44 42 41 41
  155    50 50 49 47 44 41 38 34 31 28 26 24 23 22 21 20 20 20 20 20 20 20 21 22 23 24 26 28 31 34 38 41 44 47 49 50 50
  160    38 38 38 37 35 34 33 31 30 28 27 26 25 24 24 23 23 23 23 23 23 23 24 24 25 26 27 28 30 31 33 34 35 37 38 38 38
  165    34 34 34 34 33 33 32 32 31 30 30 29 29 29 28 28 28 28 28 28 28 28 28 29 29 29 30 30 31 32 32 33 33 34 34 34 34
  170    37 37 37 37 37 37 36 36 36 36 36 35 35 35 35 35 35 35 34 35 35 35 35 35 35 35 36 36 36 36 36 37 37 37 37 37 37
  175    47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 46 46 46 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47 47
  180   117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117117

                 GAIN DEGRADATION IS
                   -8.317
```

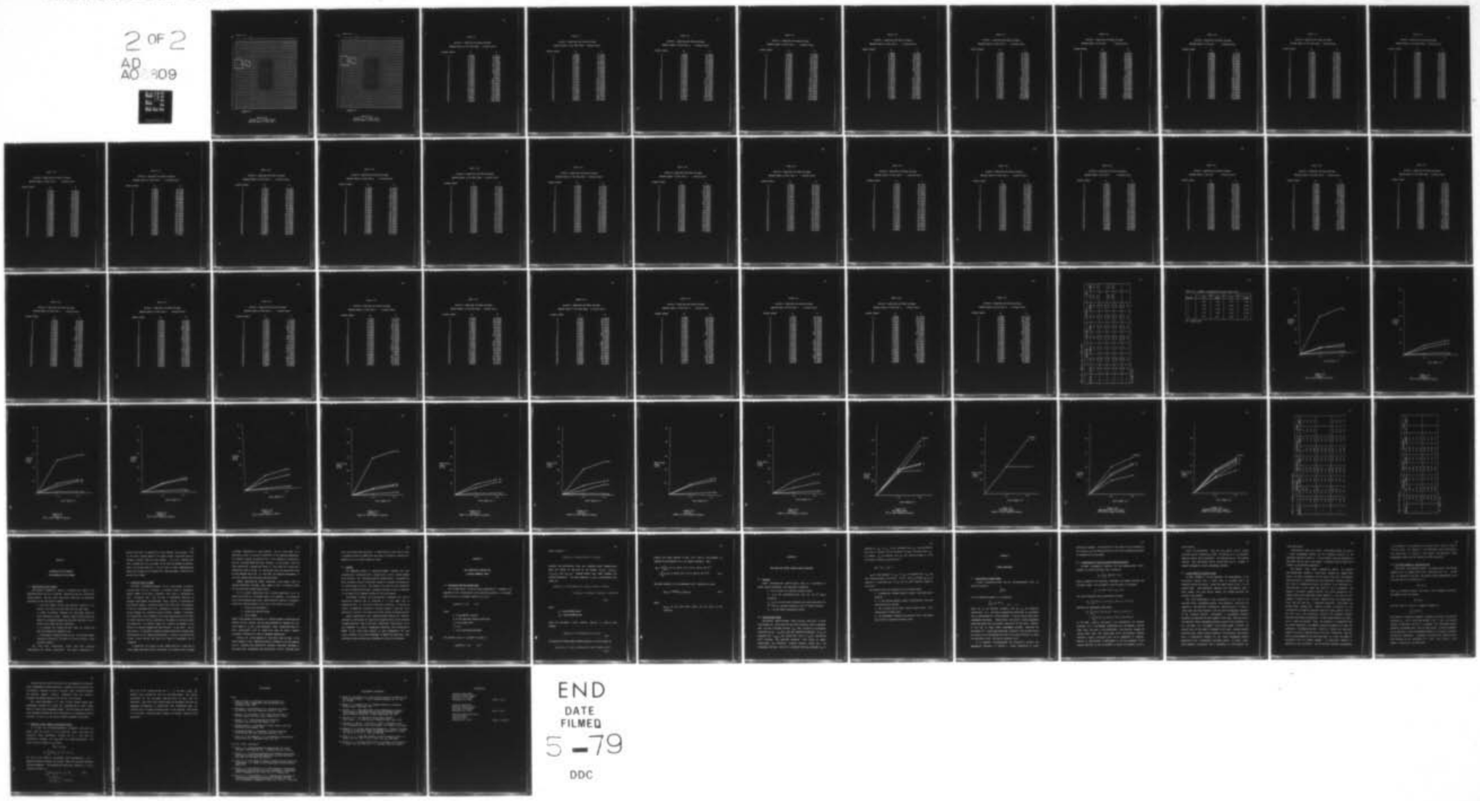
Figure 4.42
Pattern 5. 1 Percent Error
Maximum Impact on Side Lobe 1

```
              BORESIGHT AT 90,90
THETA                                 PHI
            0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0     111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
   5      41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41
  10      31 31 31 31 31 31 30 30 30 30 30 30 29 29 29 29 29 29 29 29 29 29 29 29 29 30 30 30 30 30 30 31 31 31 31 31 31
  15      28 28 28 28 27 27 26 26 25 24 24 23 23 23 22 22 22 22 22 22 22 22 22 23 23 23 24 24 25 26 26 27 27 28 28 28 28
  20      34 34 33 32 30 29 27 25 24 22 21 20 19 19 19 19 19 18 18 18 19 19 19 19 19 20 21 22 24 25 27 29 30 32 33 34 34
  25      41 41 41 42 41 38 34 30 26 23 21 19 18 17 16 16 16 15 15 15 16 16 16 17 18 19 21 23 26 30 34 38 41 42 41 41 41
  30      54 56 77 53 47 45 43 38 32 26 22 19 18 16 15 14 14 14 14 14 14 14 15 16 18 19 22 26 32 38 43 45 47 53 77 56 54
  35      35 35 35 37 38 40 41 40 35 30 24 20 18 16 15 14 14 14 14 14 14 14 15 16 19 20 24 30 35 40 41 40 38 37 35 35 35
  40      42 42 41 39 37 35 35 35 34 30 26 22 19 18 17 17 17 18 18 18 17 17 17 18 19 22 26 30 34 35 35 35 37 39 41 42 42
  45      27 27 27 27 26 26 27 29 33 31 26 24 22 19 17 15 15 15 15 15 15 15 17 19 22 24 26 31 33 29 27 26 26 27 27 27 27
  50      25 25 26 27 25 23 22 23 27 38 28 27 23 15 10  7  6  6  6  6  6  7 10 15 23 27 28 38 27 23 22 23 25 27 26 25 25
  55      21 22 23 26 30 28 24 22 24 35 29 29 22 11  6  3  2  2  2  2  2  3  6 11 22 29 29 35 24 22 24 28 30 26 23 22 21
  60      22 22 22 24 27 34 32 26 26 34 27 27 23 10  4  1  0  0  0  0  0  1  4 10 23 27 27 34 26 26 32 34 27 24 22 22 22
  65      26 26 26 26 28 31 45 36 34 54 29 28 25 12  5  2  1  1  1  1  1  2  5 12 25 28 29 54 34 36 45 31 28 26 26 26 26
  70      32 31 30 30 30 31 36 35 31 34 38 32 26 13  7  3  1  1  1  1  1  3  7 13 26 32 38 34 31 35 36 31 30 30 30 31 32
  75      38 38 36 34 33 35 36 31 27 30 40 27 25 13  6  2  0  0  0  0  0  2  6 13 25 27 40 30 27 31 36 35 33 34 36 38 38
  80      47 46 42 39 37 38 41 32 27 29 37 28 29 13  5  1  0  0  1  0  0  1  5 13 29 28 37 29 27 32 41 38 37 39 42 46 47
  85      53 47 39 34 30 28 29 33 31 27 28 34 25 13  6  2  0  0  1  0  0  2  6 13 25 34 28 27 31 33 29 28 30 34 39 47 53
  90     123 51 39 32 28 26 26 31 34 26 26 30 22 12  6  2  0  0  0  0  0  2  6 12 22 30 26 26 34 31 26 26 28 32 39 51123
  95      53 47 39 34 30 28 29 33 31 27 28 34 25 13  6  2  0  0  1  0  0  2  6 13 25 34 28 27 31 33 29 28 30 34 39 47 53
 100      47 46 42 39 37 38 41 32 27 29 37 28 29 13  5  1  0  0  1  0  0  1  5 13 29 28 37 29 27 32 41 38 37 39 42 46 47
 105      38 38 36 34 33 35 36 31 27 30 40 27 25 13  6  2  0  0  0  0  0  2  6 13 25 27 40 30 27 31 36 35 33 34 36 38 38
 110      32 31 30 30 30 31 35 35 31 34 38 32 26 13  7  3  1  1  1  1  1  3  7 13 26 32 38 34 31 35 36 31 30 30 30 31 32
 115      26 26 26 26 28 31 45 36 34 54 29 28 25 12  5  2  1  1  1  1  1  2  5 12 25 28 29 54 34 36 45 31 28 26 26 26 26
 120      22 22 22 24 27 34 32 26 26 34 27 27 23 10  4  1  0  0  0  0  0  1  4 10 23 27 27 34 26 26 32 34 27 24 22 22 22
 125      21 22 23 26 30 28 24 22 24 35 29 29 22 11  6  3  2  2  2  2  2  3  6 11 22 29 29 35 24 22 24 28 30 26 23 22 21
 130      25 25 26 27 25 23 22 23 27 38 28 27 23 15 10  7  6  6  6  6  5  7 10 15 23 27 28 38 27 23 22 23 25 27 26 25 25
 135      27 27 27 27 26 26 27 29 33 31 26 24 22 19 17 15 15 15 15 15 15 15 17 19 22 24 26 31 33 29 27 26 26 27 27 27 27
 140      42 42 41 39 37 35 35 35 34 30 26 22 19 18 17 17 17 18 18 18 17 17 17 18 19 22 26 30 34 35 35 35 37 39 41 42 42
 145      35 35 35 37 38 40 41 40 35 30 24 20 18 16 15 14 14 14 14 14 14 14 15 16 18 20 24 30 35 40 41 40 38 37 35 35 35
 150      54 56 77 53 47 45 43 38 32 26 22 19 18 16 15 14 14 14 14 14 14 14 15 16 18 19 22 26 32 38 43 45 47 53 77 56 54
 155      41 41 41 42 41 38 34 30 26 23 21 19 18 17 16 16 16 15 15 15 16 16 16 17 18 19 21 23 26 30 34 38 41 42 41 41 41
 160      34 34 33 32 30 29 27 25 24 22 21 20 19 19 19 19 19 18 18 18 19 19 19 19 19 20 21 22 24 25 27 29 30 32 33 34 34
 165      28 28 28 28 27 27 26 26 25 24 24 23 23 23 22 22 22 22 22 22 22 22 22 23 23 23 24 24 25 26 26 27 27 28 28 28 28
 170      31 31 31 31 31 31 30 30 30 30 30 30 29 29 29 29 29 29 29 29 29 29 29 29 29 30 30 30 30 30 30 31 31 31 31 31 31
 175      41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41
 180     111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111

                    GAIN DEGRADATION IS
                      -8.186
```

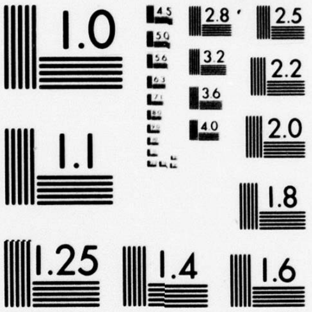
Figure 4.43
Pattern 5. 2 Percent Error
Maximum Impact on Side Lobe 1

AD-A066 098 PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESE--ETC F/G 17/1
SENSITIVITY ANALYSIS IN LARGE SCALE MULTI-OBJECTIVE SYSTEMS.(U)
SEP 78 J H PERLIS N00017-73-C-1418
UNCLASSIFIED ARL/PSU/TM-78-302 NL

2 OF 2
AD
A0 809



END
DATE
FILMED
5-79
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
          BORESIGHT AT 90,30

THETA                         PHI

       0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

   0 128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128
   5  58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58
  10  52 52 52 51 51 50 50 49 48 48 47 47 46 46 45 45 45 45 45 45 45 45 45 46 46 47 47 48 48 49 50 50 51 51 52 52 52
  15  53 53 54 56 57 56 53 50 48 45 44 42 41 40 39 38 38 38 37 38 38 38 39 40 41 42 44 45 48 50 53 56 57 56 54 53 53
  20  37 37 38 38 39 40 42 45 49 49 44 41 38 36 35 34 33 33 33 33 33 34 35 36 38 41 44 49 49 45 42 40 39 38 38 37 37
  25  32 32 32 32 33 33 34 35 37 40 42 40 36 34 32 30 30 29 29 29 30 30 32 34 36 40 42 40 37 35 34 33 33 32 32 32 32
  30  32 32 31 31 31 31 31 31 32 33 35 36 34 32 30 28 28 27 27 27 28 28 30 32 34 36 35 33 32 31 31 31 31 31 31 32 32
  35  29 30 30 30 30 30 30 30 30 30 30 32 32 32 31 31 30 30 30 30 30 31 31 32 32 32 30 30 30 30 30 30 30 30 30 30 29
  40  23 23 24 24 25 26 27 28 29 29 29 29 31 34 32 29 28 27 27 27 28 29 32 34 31 29 29 29 29 28 27 26 25 24 24 23 23
  45  20 20 20 20 20 21 22 24 27 29 29 29 27 21 18 15 14 14 14 14 14 15 18 21 27 29 29 29 27 24 22 21 20 20 20 20 20
  50  21 21 21 20 20 19 19 20 23 27 28 31 23 15 10  8  7  6  6  6  7  8 10 15 23 31 28 27 23 20 19 19 20 20 21 21 21
  55  21 21 21 23 24 23 21 20 22 26 27 30 22 12  6  3  2  2  2  2  2  3  6 12 22 30 27 26 22 20 21 23 24 23 21 21 21
  60  19 19 19 20 22 25 29 26 25 28 26 27 24 11  5  2  1  0  1  0  1  2  5 11 24 27 26 28 25 26 29 25 22 20 19 19 19
  65  22 22 22 21 22 23 27 35 60 39 29 28 23 12  6  2  1  1  1  1  1  2  6 12 23 28 29 39 60 35 27 23 22 21 22 22 22
  70  32 32 31 30 29 29 29 28 27 29 34 40 22 12  6  3  1  1  1  1  1  3  6 12 22 40 34 29 27 28 29 29 29 30 31 32 32
  75  37 37 35 33 33 35 54 32 27 27 36 32 22 12  5  1  0  0  0  0  0  1  5 12 22 32 36 27 27 32 54 35 33 33 35 37 37
  80  41 39 36 32 29 29 31 40 34 32 51 31 24 12  5  1  0  0  0  0  0  1  5 12 24 31 51 32 34 40 31 29 29 32 36 39 41
  85  55 49 41 35 31 30 30 35 38 32 33 45 23 13  6  2  1  1  1  1  1  2  6 13 23 45 33 32 38 35 30 30 31 35 41 49 55
  90 130 56 44 37 33 31 31 34 32 28 29 42 21 12  6  3  1  0  0  0  1  3  6 12 21 42 29 28 32 34 31 31 33 37 44 55130
  95  55 49 41 35 31 30 30 35 38 32 33 45 23 13  6  2  1  1  1  1  1  2  6 13 23 45 33 32 38 35 30 30 31 35 41 49 55
 100  41 39 36 32 29 29 31 40 34 32 51 31 24 12  5  1  0  0  0  0  0  1  5 12 24 31 51 32 34 40 31 29 29 32 36 39 41
 105  37 37 35 33 33 35 54 32 27 27 36 32 22 12  5  1  0  0  0  0  0  1  5 12 22 32 36 27 27 32 54 35 33 33 35 37 37
 110  32 32 31 30 29 29 29 28 27 29 34 40 22 12  6  3  1  1  1  1  1  3  6 12 22 40 34 29 27 28 29 29 29 30 31 32 32
 115  22 22 22 21 22 23 27 35 60 39 29 28 23 12  6  2  1  1  1  1  1  2  6 12 23 28 29 39 60 35 27 23 22 21 22 22 22
 120  19 19 19 20 22 25 29 26 25 28 26 27 24 11  5  2  1  0  1  0  1  2  5 11 24 27 26 28 25 26 29 25 22 20 19 19 19
 125  21 21 21 23 24 23 21 20 22 26 27 30 22 12  6  3  2  2  2  2  2  3  6 12 22 30 27 26 22 20 21 23 24 23 21 21 21
 130  21 21 21 20 20 19 19 20 23 27 28 31 23 15 10  8  7  6  6  6  7  8 10 15 23 31 28 27 23 20 19 19 20 20 21 21 21
 135  20 20 20 20 20 21 22 24 27 29 29 29 27 21 18 15 14 14 14 14 14 15 18 21 27 29 29 29 27 24 22 21 20 20 20 20 20
 140  23 23 24 24 25 26 27 28 29 29 29 29 31 34 32 29 28 27 27 27 28 29 32 34 31 29 29 29 29 28 27 26 25 24 24 23 23
 145  29 30 30 30 30 30 30 30 30 30 30 32 32 32 31 31 30 30 30 30 30 31 31 32 32 32 30 30 30 30 30 30 30 30 30 30 29
 150  32 32 31 31 31 31 31 31 32 33 35 36 34 32 30 28 28 27 27 27 28 28 30 32 34 36 35 33 32 31 31 31 31 31 31 32 32
 155  32 32 32 32 33 33 34 35 37 40 42 40 36 34 32 30 30 29 29 29 30 30 32 34 36 40 42 40 37 35 34 33 33 32 32 32 32
 160  37 37 38 38 39 40 42 45 49 49 44 41 38 36 35 34 33 33 33 33 33 34 35 36 38 41 44 49 49 45 42 40 39 38 38 37 37
 165  53 53 54 56 57 56 53 50 48 45 44 42 41 40 39 38 38 38 37 38 38 38 39 40 41 42 44 45 48 50 53 56 57 56 54 53 53
 170  52 52 52 51 51 50 50 49 48 48 47 47 46 46 45 45 45 45 45 45 45 45 45 46 46 47 47 48 48 49 50 50 51 51 52 52 52
 175  58 58 58 58 58 58 58 58 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 57 58 58 58 58 58 58 58 58
 180 128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128128

             GAIN DEGRADATION IS
                -8.537
```

Figure 4.44
Pattern 5. 1 Percent Error
Maximum Impact on Side Lobe 2

```
        BORESIGHT AT 90,90
THETA                                 PHI
           0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 00 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

    0    130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130
    5     56 56 56 56 56 56 56 56 57 57 57 57 57 57 57 57 58 58 58 58 58 57 57 57 57 57 57 57 57 56 56 56 56 56 56 56 56
   10     43 43 43 43 43 43 43 43 43 43 43 44 44 44 45 45 45 45 46 45 45 45 45 44 44 44 43 43 43 43 43 43 43 43 43 43 43
   15     40 40 40 39 39 39 38 37 37 36 36 36 36 36 37 37 38 38 38 38 38 37 37 36 36 36 36 36 37 37 38 39 39 39 40 40 40
   20     30 30 31 31 32 33 34 35 35 34 33 32 31 31 31 32 32 33 33 33 32 32 31 31 31 32 33 34 35 35 34 33 32 31 31 30 30
   25     24 24 24 24 25 25 26 27 28 30 31 30 28 27 27 27 28 29 29 29 28 27 27 27 28 30 31 30 28 27 26 25 25 24 24 24 24
   30     23 23 23 23 22 22 22 23 23 25 26 27 27 26 25 25 25 26 26 26 25 25 25 26 27 27 26 25 23 23 22 22 22 23 23 23 23
   35     21 21 21 21 21 21 21 21 21 22 23 24 25 26 26 26 27 27 27 27 27 26 26 26 25 24 23 22 21 21 21 21 21 21 21 21 21
   40     18 18 18 18 18 18 19 20 21 21 22 23 23 24 25 25 24 24 24 24 24 25 25 24 23 23 22 21 21 20 19 18 18 18 18 18 18
   45     15 15 15 15 15 16 16 18 19 21 22 23 22 18 15 13 12 13 13 13 12 13 15 18 22 23 22 21 19 18 16 16 15 15 15 15 15
   50     17 17 16 16 15 15 15 15 17 19 23 25 20 13  8  6  5  5  5  5  5  6  8 13 20 25 23 19 17 15 15 15 15 16 16 17 17
   55     18 18 18 18 18 18 17 16 17 19 23 28 20 10  5  2  1  1  1  1  1  2  5 10 20 28 23 19 17 16 17 18 18 18 18 18 18
   60     16 16 16 17 18 19 22 22 21 22 24 27 22 10  4  1  0  0  0  0  0  1  4 10 22 27 24 22 21 22 22 19 18 17 16 16 16
   65     18 18 18 18 18 18 20 24 29 30 26 26 21 11  5  1  0  0  0  0  0  1  5 11 21 26 26 30 29 24 20 18 18 18 18 18 18
   70     28 28 27 26 24 24 23 22 22 24 27 29 19 11  5  2  0  0  0  0  0  2  5 11 19 29 27 24 22 22 23 24 24 26 27 28 28
   75     39 39 37 35 36 40 37 28 24 24 28 29 19 10  4  0  0  0  0  0  0  0  4 10 19 29 28 24 24 28 37 40 36 35 37 39 39
   80     39 37 34 30 27 26 27 30 32 31 35 28 21 11  4  1  0  0  0  0  0  1  4 11 21 28 35 31 32 30 27 26 27 30 34 37 39
   85     51 45 37 31 27 25 25 28 35 33 34 31 23 12  5  2  0  0  0  0  0  2  5 12 23 31 34 33 35 28 25 25 27 31 37 45 51
   90    123 51 39 32 28 26 26 29 30 27 29 36 23 13  6  2  0  0  0  0  0  2  6 13 23 36 29 27 30 28 26 26 28 32 39 51123
   95     51 45 37 31 27 25 25 28 35 33 34 31 23 12  5  2  0  0  0  0  0  2  5 12 23 31 34 33 35 28 25 25 27 31 37 45 51
  100     39 37 34 30 27 26 27 30 32 31 35 28 21 11  4  1  0  0  0  0  0  1  4 11 21 28 35 31 32 30 27 26 27 30 34 37 39
  105     39 39 37 35 36 40 37 28 24 24 28 29 19 10  4  0  0  0  0  0  0  0  4 10 19 29 28 24 24 28 37 40 36 35 37 39 39
  110     28 28 27 26 24 24 23 22 22 24 27 29 19 11  5  2  0  0  0  0  0  2  5 11 19 29 27 24 22 22 23 24 24 26 27 28 28
  115     18 18 18 18 18 18 20 24 29 30 26 26 21 11  5  1  0  0  0  0  0  1  5 11 21 26 26 30 29 24 20 18 18 18 18 18 18
  120     16 16 16 17 18 19 22 22 21 22 24 27 22 10  4  1  0  0  0  0  0  1  4 10 22 27 24 22 21 22 22 19 18 17 16 16 16
  125     18 18 18 18 18 18 17 16 17 19 23 28 20 10  5  2  1  1  1  1  1  2  5 10 20 28 23 19 17 16 17 18 18 18 18 18 18
  130     17 17 16 16 15 15 15 15 17 19 23 25 20 13  8  6  5  5  5  5  5  6  8 13 20 25 23 19 17 15 15 15 15 16 16 17 17
  135     15 15 15 15 15 16 16 18 19 21 22 23 22 18 15 13 12 13 13 13 12 13 15 18 22 23 22 21 19 18 16 16 15 15 15 15 15
  140     18 18 18 18 18 18 19 20 21 21 22 23 23 24 25 25 24 24 24 24 24 25 25 24 23 23 22 21 21 20 19 19 18 18 18 18 18
  145     21 21 21 21 21 21 21 21 21 22 23 24 25 26 26 26 27 27 27 27 27 26 26 26 25 24 23 22 21 21 21 21 21 21 21 21 21
  150     23 23 23 23 22 22 22 23 23 25 26 27 27 26 25 25 25 26 26 26 25 25 25 26 27 27 26 25 23 23 22 22 22 23 23 23 23
  155     24 24 24 24 25 25 26 27 28 30 31 30 28 27 27 27 28 29 29 29 28 27 27 27 28 30 31 30 28 27 26 25 25 24 24 24 24
  160     30 30 31 31 32 33 34 35 35 34 33 32 31 31 31 32 32 33 33 33 32 32 31 31 31 32 33 34 35 35 34 33 32 31 31 30 30
  165     40 40 40 39 39 39 38 37 37 36 36 36 36 36 37 37 38 38 38 38 38 37 37 36 36 36 36 36 37 37 38 39 39 39 40 40 40
  170     43 43 43 43 43 43 43 43 43 43 43 44 44 44 45 45 45 45 46 45 45 45 45 44 44 44 43 43 43 43 43 43 43 43 43 43 43
  175     56 56 56 56 56 56 56 56 57 57 57 57 57 57 57 57 58 58 58 58 58 57 57 57 57 57 57 57 57 56 56 56 56 56 56 56 56
  180    130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130130

                GAIN DEGRADATION IS
                 -8.546
```

Figure 4.45
Pattern 5. 2 Percent Error
Maximum Impact on Side Lobe 2

Table 4.6

Pattern 1 Amplitude and Phase Settings

Maximum Impact on the Main Beam. 1 percent error.

Element Number	A_i	α_i
1	0.99001	41.49132
2	0.81989	46.88094
3	0.54476	57.98431
4	0.29153	77.83815
5	0.13375	121.66500
6	0.74183	25.63405
7	0.56344	37.32784
8	0.37299	43.03300
9	0.18821	82.60611
10	0.01031	-19.88239
11	0.48664	8.66110
12	0.32213	7.94737
13	0.16964	10.60483
14	0.05548	-69.35330
15	0.02564	-107.34150
16	0.36302	-23.98924
17	0.23218	-54.83496
18	0.17712	-54.10857
19	-0.00683	-100.55660
20	0.04657	-91.89992
21	0.18199	-75.43584
22	0.15151	-53.00188
23	0.08324	-112.88140
24	0.01772	-103.04570
25	0.00364	-155.93350

Table 4.7

Pattern 1. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 2 Percent Error.

Element Number	A_i	α_i
1	0.98007	37.91867
2	0.80996	43.30829
3	0.53490	54.41331
4	0.30084	74.26247
5	0.12382	118.08930
6	0.75111	22.06139
7	0.57337	33.75526
8	0.38292	39.46039
9	0.19814	79.03043
10	0.02023	-16.30980
11	0.49657	12.23315
12	0.33206	11.51942
13	0.17957	14.17688
14	0.04555	-65.77925
15	0.01571	-103.76740
16	0.37295	-20.41682
17	0.22225	-51.26228
18	0.18361	-50.53598
19	-0.01676	-103.90100
20	0.03664	-88.32588
21	0.17206	-71.86179
22	0.14157	-49.42924
23	0.07331	-109.30740
24	0.00779	-99.47165
25	-0.00629	-153.67570

Table 4.8

Pattern 1. Amplitude and Phase settings.

Maximum Impact on Side lobe 1. 1 Percent Error.

Element Number	A_i	α_i
1	1.00994	48.68059
2	0.83987	54.07021
3	0.54873	65.17307
4	0.27155	85.02690
5	0.15368	128.85380
6	0.72184	25.63399
7	0.54346	37.32780
8	0.35301	43.03294
9	0.18796	82.72293
10	0.01031	-19.90404
11	0.46666	8.66104
12	0.30215	7.94732
13	0.14966	10.60477
14	0.07143	-76.54237
15	0.04562	-114.53050
16	0.36302	-31.17850
17	0.25216	-62.02150
18	0.19710	-61.29488
19	0.01315	-93.37694
20	0.06655	-98.86388
21	0.20197	-82.62491
22	0.17149	-60.18817
23	0.08324	-120.07050
24	0.01772	-110.23470
25	0.01760	-156.83910

Table 4.9

Pattern 1. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 2 Percent Error.

Element Number	A_i	α_i
1	1.01985	52.25250
2	0.84979	57.63838
3	0.53490	68.74329
4	0.26162	88.59712
5	0.12382	132.42400
6	0.71192	22.06139
7	0.53353	33.75526
8	0.36832	39.46039
9	0.19814	89.43881
10	-0.01318	-19.15211
11	0.45673	12.23315
12	0.29222	11.51942
13	0.13973	14.17688
14	0.08538	-80.11287
15	0.05555	-118.10100
16	0.37295	-34.75050
17	0.26209	-65.59200
18	0.20703	-64.86537
19	0.02307	-100.20710
20	0.07647	-102.61650
21	0.21190	-86.19540
22	0.18141	-63.75867
23	0.07331	-123.64100
24	0.00779	-113.80520
25	0.02713	-160.40960

Table 4.10

Pattern 1. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2.   1 Percent Error.

Element Number	A_i	α_i
1	1.00961	41.74815
2	0.82021	53.95192
3	0.56436	58.09955
4	0.29120	84.90733
5	0.13407	128.73420
6	0.74150	32.70503
7	0.54379	44.39886
8	0.37266	43.15051
9	0.18788	89.67531
10	-0.00059	-26.80592
11	0.48631	8.54297
12	0.30248	0.87618
13	0.16931	3.53352
14	0.05580	-76.27386
15	0.04529	-114.38990
16	0.36269	-24.10683
17	0.24270	-61.90031
18	0.19677	-54.22615
19	-0.00651	-93.50945
20	0.06622	-98.96780
21	0.18231	-75.55025
22	0.15183	-60.06697
23	0.10313	-112.99580
24	0.01804	-110.11350
25	0.02329	-149.76440

Table 4.11

Pattern 1. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 2 Percent Error.

Element Number	A_i	α_i
1	1.01988	52.25273
2	0.80996	57.64056
3	0.57462	54.41354
4	0.30146	88.59930
5	0.12382	132.42620
6	0.75175	36.39546
7	0.53353	33.75549
8	0.38292	39.46065
9	0.19814	93.36726
10	0.02024	-30.64375
11	0.49657	12.23329
12	0.29222	-2.81394
13	0.17957	-0.15656
14	0.04555	-80.11456
15	0.05555	-103.83400
16	0.36733	-20.41698
17	0.26209	-65.59369
18	0.20703	-50.53621
19	-0.01676	-93.19521
20	0.07647	-100.87590
21	0.17206	-71.86348
22	0.18135	-63.76036
23	0.07893	-109.30900
24	0.00779	-113.80690
25	0.03355	-146.07760

Table 4.12

Pattern 1. Amplitude and Phase settings.

Maximum Impact on the Null.   1 Percent Error.

Element Number	A_i	α_i
1	0.99021	41.49115
2	0.81994	52.09497
3	0.56463	65.17279
4	0.29153	85.02663
5	0.15373	128.85350
6	0.72342	32.82320
7	0.54346	44.51698
8	0.35323	43.03284
9	0.16823	82.72266
10	0.01031	-27.07143
11	0.48664	1.47198
12	0.30764	0.75828
13	0.14966	10.60474
14	0.05548	-76.54156
15	0.02570	-114.52970
16	0.34304	-23.98907
17	0.23218	-62.02069
18	0.19710	-59.32150
19	0.01315	-93.49113
20	0.06655	-92.01680
21	0.20197	-75.55272
22	0.17149	-60.11172
23	0.08329	-120.06970
24	0.01772	-110.23390
25	0.02362	-156.83830

Table 4.13

Pattern 1. Amplitude and Phase settings.

Maximum Impact on the Null. 2 Percent Error.

Element Number	A_i	α_i
1	0.98647	37.91867
2	0.81008	53.71478
3	0.57450	68.74329
4	0.30146	88.59712
5	0.16365	132.42400
6	0.71232	36.39523
7	0.53353	48.08904
8	0.34950	39.46039
9	0.15830	79.03043
10	0.02023	-30.64362
11	0.49657	-2.10023
12	0.30314	-2.81393
13	0.13973	14.17688
14	0.04555	-80.11287
15	0.01583	-118.10100
16	0.33311	-20.41682
17	0.22225	-65.59200
18	0.20703	-60.94119
19	0.02307	-89.80022
20	0.07647	-88.32588
21	0.21190	-71.86179
22	0.18141	-61.45319
23	0.07343	-123.64100
24	0.00779	-113.80520
25	0.03355	-160.40960

Table 4.14

Pattern 2. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 1 Percent Error.

Element Number	A_i	α_i
1	0.99001	82.99451
2	0.71493	72.69763
3	0.41100	42.82335
4	0.22526	-13.39055
5	0.15096	-55.64073
6	0.66943	78.32292
7	0.50047	59.45757
8	0.24733	17.08455
9	0.25547	-29.58571
10	0.12430	-48.79063
11	0.25718	55.11913
12	0.22163	16.72641
13	0.28098	-5.35801
14	0.22563	-32.30592
15	0.12461	-58.47069
16	0.15506	-27.54604
17	0.15947	-25.03529
18	0.22672	-33.80103
19	0.13454	-50.83426
20	0.01818	-64.63976
21	0.12854	-62.08603
22	0.10943	-50.34950
23	0.05815	-44.35547
24	0.06849	-60.85086
25	-0.00923	-81.58513

Table 4.15

Pattern 2. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 2 Percent Error.

Element Number	A_i	α_i
1	0.98008	79.42007
2	0.70500	69.12321
3	0.42092	39.25085
4	0.23519	-9.81820
5	0.14103	-52.06812
6	0.65950	74.74850
7	0.51040	55.88519
8	0.25725	15.54277
9	0.26540	-26.01320
10	0.12097	-45.21815
11	0.26710	51.54634
12	0.23156	14.19118
13	0.29091	-1.78578
14	0.23555	-28.73344
15	0.11468	-54.89915
16	0.16498	-23.97356
17	0.16940	-21.46283
18	0.23665	-30.22852
19	0.12461	-47.26175
20	0.00825	-61.06621
21	0.11861	-58.51248
22	0.11317	-46.77702
23	0.06899	-40.78296
24	0.05857	-57.27869
25	-0.01916	-85.18558

Table 4.16

Pattern 2. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 1 Percent Error.

Element Number	A_i	α_i
1	0.99001	82.99374
2	0.71493	72.69687
3	0.39101	42.82324
4	0.22526	-20.57953
5	0.17094	-62.80807
6	0.68941	85.51195
7	0.50047	66.64658
8	0.22735	22.23720
9	0.23549	-29.58563
10	0.12430	-55.97975
11	0.23719	55.11902
12	0.22163	15.79092
13	0.28098	-12.54722
14	0.22563	-39.49507
15	0.14459	-62.30493
16	0.13508	-27.54596
17	0.13949	-25.03519
18	0.20674	-33.80095
19	0.13454	-58.02119
20	0.01818	-71.82802
21	0.14852	-62.08505
22	0.12908	-57.53702
23	0.07780	-51.54457
24	0.08847	-61.31598
25	0.01075	-74.48824

Table 4.17

Pattern 2. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 2 Percent Error.

Element Number	A_i	α_i
1	0.98007	79.41789
2	0.70500	69.12102
3	0.38108	39.25060
4	0.23518	-24.15146
5	0.18087	-66.35463
6	0.69933	89.08096
7	0.51039	70.21561
8	0.21741	25.80904
9	0.22556	-26.01297
10	0.11437	-59.54799
11	0.22726	51.54608
12	0.23156	12.21849
13	0.29091	-16.11913
14	0.23555	-43.06696
15	0.15451	-65.30235
16	0.12515	-23.97336
17	0.12956	-21.46260
18	0.19681	-30.22830
19	0.12461	-61.59137
20	0.00825	-75.39813
21	0.15845	-66.00323
22	0.13901	-61.10658
23	0.08773	-55.11650
24	0.09840	-67.68253
25	0.02067	-71.09834

Table 4.18

Pattern 2. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2.   1 Percent Error.

Element Number	A_i	α_i
1	1.00995	83.11012
2	0.71493	79.88518
3	0.41099	42.82304
4	0.20528	-13.39043
5	0.17094	-62.82626
6	0.66943	85.51047
7	0.50047	59.57318
8	0.22734	15.04794
9	0.25547	-36.77461
10	0.13350	-48.79034
11	0.25717	55.19592
12	0.20165	15.79082
13	0.28098	-5.35789
14	0.20837	-32.30568
15	0.14459	-65.65773
16	0.15505	-34.65994
17	0.13949	-32.22432
18	0.22672	-33.80075
19	0.13454	-58.02000
20	0.01818	-71.82681
21	0.14852	-69.27309
22	0.12908	-50.34926
23	0.05782	-51.54437
24	0.08847	-68.03792
25	-0.00923	-81.67628

Table 4.19

Pattern 2. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 2 Percent Error.

Element Number	A_i	α_i
1	1.01983	79.41620
2	0.70500	83.45398
3	0.42092	39.25041
4	0.19535	-9.81802
5	0.18086	-66.39648
6	0.65949	89.07927
7	0.51039	55.88481
8	0.21741	11.47547
9	0.26539	-40.34660
10	0.14813	-45.21776
11	0.26710	52.10831
12	0.19172	12.21839
13	0.29090	-1.78575
14	0.22138	-28.73311
15	0.15451	-69.22795
16	0.16498	-37.74136
17	0.12956	-35.79630
18	0.23664	-30.22812
19	0.12461	-61.59027
20	0.00825	-75.39703
21	0.15845	-72.84331
22	0.13901	-46.77669
23	0.04789	-55.11636
24	0.09840	-71.60814
25	-0.01916	-85.24651

Table 4.20

Pattern 3. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 1 Percent Error.

Element Number	A_i	α_i
1	0.99033	83.10712
2	0.71665	72.81026
3	0.35546	47.94011
4	0.24539	-18.50732
5	0.15889	-40.51294
6	0.68453	78.43555
7	0.48179	59.57018
8	0.25729	16.45805
9	0.24596	-27.14305
10	0.14811	-57.90044
11	0.25928	55.23537
12	0.20170	17.95587
13	0.27051	-5.47562
14	0.21723	-37.42282
15	0.09138	-48.98233
16	0.15109	-31.51103
17	0.15355	-22.71280
18	0.21828	-33.91832
19	0.12946	-45.95184
20	0.04597	-54.51227
21	0.10977	-65.39644
22	0.10497	-53.82712
23	0.07493	-40.11311
24	0.06588	-47.36270
25	-0.00894	-76.95766

Table 4.21

Pattern 3. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 2 Percent Error.

Element Number	A_i	α_i
1	0.98008	79.41866
2	0.70639	69.12178
3	0.36572	44.25023
4	0.25565	-14.81753
5	0.16914	-36.82297
6	0.67427	74.74707
7	0.49204	55.88377
8	0.26755	15.53319
9	0.25621	-23.45320
10	0.13786	-54.21576
11	0.26953	51.54518
12	0.21196	15.02099
13	0.28077	-1.78571
14	0.22749	-33.73288
15	0.08113	-45.29236
16	0.16135	-27.82106
17	0.16381	-19.02280
18	0.22854	-30.22832
19	0.11921	-42.26193
20	0.03571	-50.82227
21	0.09952	-61.70944
22	0.09588	-50.13727
23	0.07958	-36.42317
24	0.05563	-43.67273
25	-0.01919	-80.56252

Table 4.22

Pattern 3. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 1 Percent Error.

Element Number	A_i	α_i
1	0.99001	90.18063
2	0.71632	79.88376
3	0.33603	55.01173
4	0.22574	-18.38959
5	0.13924	-40.39520
6	0.70418	85.48949
7	0.48212	66.64369
8	0.23764	15.04776
9	0.24629	-34.21460
10	0.16777	-64.97406
11	0.23963	55.11768
12	0.18205	17.83820
13	0.25108	-5.35782
14	0.19758	-37.30504
15	0.09105	-48.86459
16	0.13144	-31.39325
17	0.13390	-22.59503
18	0.21861	-40.98973
19	0.14912	-53.02333
20	0.06562	-61.58011
21	0.12943	-72.47006
22	0.12463	-60.89513
23	0.05528	-39.99532
24	0.06556	-47.24496
25	-0.00926	-77.05322

Table 4.23

Pattern 3. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1.   2 Percent Error.

Element Number	A_i	α_i
1	0.98007	93.75113
2	0.70639	83.45425
3	0.33230	58.57985
4	0.21581	-14.81742
5	0.12931	-36.82277
6	0.71411	89.03709
7	0.49204	70.21419
8	0.22771	11.47540
9	0.25621	-37.78667
10	0.17770	-68.54538
11	0.22970	51.54495
12	0.17212	14.26602
13	0.24735	-1.78570
14	0.18765	-33.73273
15	0.08113	-45.29216
16	0.12151	-27.82083
17	0.12397	-19.02257
18	0.22854	-44.56186
19	0.15904	-56.59546
20	0.07554	-65.15143
21	0.13935	-76.04137
22	0.13455	-64.46645
23	0.04536	-42.61943
24	0.05563	-43.67253
25	-0.01919	-79.54712

Table 4.24

Pattern 3. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 1 Percent Error.

Element Number	A_i	α_i
1	1.00995	90.18057
2	0.71632	72.81178
3	0.33581	55.01170
4	0.24572	-25.57875
5	0.15922	-47.58437
6	0.70418	85.50900
7	0.46214	59.57170
8	0.23764	22.23676
9	0.24629	-34.21460
10	0.16777	-63.57092
11	0.25961	62.30411
12	0.18205	17.83817
13	0.27084	-5.35781
14	0.19758	-44.49431
15	0.11104	-56.05379
16	0.15142	-31.39322
17	0.13390	-29.78421
18	0.21861	-33.80057
19	0.12913	-53.02332
20	0.06552	-61.57962
21	0.12943	-71.98157
22	0.10470	-60.89464
23	0.06820	-39.99530
24	0.08554	-54.43413
25	-0.00926	-69.98135

Table 4.25

Pattern 3. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2.   2 Percent Error.

Element Number	A_i	α_i
1	1.01987	93.75259
2	0.70639	69.12108
3	0.32588	58.58133
4	0.25565	-29.15099
5	0.16914	-51.03870
6	0.71411	89.08102
7	0.45221	55.88370
8	0.22771	25.80901
9	0.25621	-37.78683
10	0.17770	-68.54456
11	0.26953	65.87613
12	0.17213	14.26612
13	0.28077	-1.78570
14	0.18765	-48.06648
15	0.12096	-59.62334
16	0.16135	-27.82098
17	0.12397	-33.35643
18	0.22854	-30.22826
19	0.11920	-56.59561
20	0.06434	-65.15274
21	0.13935	-70.39001
22	0.12109	-64.46776
23	0.05657	-36.42313
24	0.09547	-58.00421
25	-0.01919	-66.29224

Table 4.26

Pattern 3. Amplitude and Phase settings.

Maximum Impact on the Null 1 Percent Error.

Element Number	A_i	α_i
1	0.99033	83.10838
2	0.71665	79.76546
3	0.33614	54.89377
4	0.24539	-18.50745
5	0.15889	-40.51306
6	0.70385	85.39075
7	0.48179	59.57143
8	0.25729	15.16562
9	0.22663	-34.09666
10	0.14812	-64.85544
11	0.25928	55.23553
12	0.18238	24.90955
13	0.25119	-5.47570
14	0.21723	-37.42291
15	0.11071	-48.98245
16	0.13176	-38.46460
17	0.15355	-22.71289
18	0.21828	-33.91841
19	0.12946	-52.90540
20	0.04597	-61.46149
21	0.12910	-72.35143
22	0.11508	-60.90169
23	0.05561	-47.04689
24	0.06588	-54.31622
25	0.01039	-69.98114

Table 4.27

Pattern 3. Amplitude and Phase settings.

Maximum Impact on the Null 2 Percent Error.

Element Number	A_i	α_i
1	0.98007	79.41647
2	0.70639	83.45425
3	0.32588	58.57985
4	0.25565	-25.22350
5	0.16914	-44.31465
6	0.71411	89.07954
7	0.49204	55.88351
8	0.26754	11.47540
9	0.21637	-37.78667
10	0.13786	-68.54538
11	0.26953	51.54495
12	0.17212	28.59955
13	0.24093	-1.78570
14	0.22749	-33.73273
15	0.12096	-45.29216
16	0.12151	-42.15465
17	0.16381	-24.37172
18	0.22854	-30.22809
19	0.11920	-56.59546
20	0.03571	-65.15143
21	0.13935	-76.04137
22	0.11554	-62.16019
23	0.04536	-50.71310
24	0.05563	-58.00290
25	0.02064	-76.69783

Table 4.28

Pattern 4. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 1 Percent Error.

Element Number	A_i	α_i
1	0.99000	80.22981
2	0.57462	71.41367
3	0.15240	30.66972
4	0.14752	-58.21255
5	0.09088	-96.90738
6	0.54779	80.69716
7	0.35826	56.28606
8	0.24028	9.77547
9	0.19048	-21.48817
10	0.09229	-73.88510
11	-0.00589	-171.35440
12	0.15118	2.71470
13	0.27176	9.15734
14	0.20907	-10.04460
15	0.09625	-8.75852
16	0.14645	-95.75626
17	0.11651	-41.43205
18	0.17666	-3.24723
19	0.15050	4.94055
20	0.02904	-6.78648
21	0.07705	-96.84164
22	0.02588	-75.27524
23	0.04555	-36.44624
24	0.03225	111.78390
25	0.02849	85.51938

Table 4.29

Pattern 4. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 2 Percent Error.

Element Number	A_i	α_i
1	0.98007	76.53784
2	0.56469	67.72171
3	0.16233	27.09732
4	0.13759	-54.52652
5	0.08095	-93.21754
6	0.53786	77.00519
7	0.36819	52.71344
8	0.25021	13.34765
9	0.20040	-17.91579
10	0.08236	-70.19528
11	-0.01582	-170.89520
12	0.16111	6.28663
13	0.28168	12.72952
14	0.21899	-6.47231
15	0.10617	-5.18623
16	0.13653	-92.06642
17	0.12637	-37.85968
18	0.18658	0.32496
19	0.16043	8.51276
20	0.03897	-3.21438
21	0.06712	-93.15181
22	0.01596	-71.58540
23	0.05548	-32.87387
24	0.04218	108.09200
25	0.03842	81.82742

Table 4.30

Pattern 4. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1.   1 Percent Error.

Element Number	A_i	α_i
1	0.99001	80.23009
2	0.57462	78.48587
3	0.13242	37.85910
4	0.14752	-65.28502
5	0.09088	-103.97980
6	0.56778	87.76935
7	0.35826	63.47284
8	0.24029	2.56845
9	0.19048	-28.67743
10	0.11227	-80.95758
11	-0.00589	-178.27770
12	0.15097	-4.47435
13	0.25178	9.15739
14	0.18909	-10.04464
15	0.07627	-8.75856
16	0.14646	-102.82870
17	0.09658	-41.43213
18	0.17666	-10.43635
19	0.15050	-2.24838
20	0.02904	-13.97578
21	0.09703	-96.84274
22	0.04586	-82.34772
23	0.02557	-43.63550
24	0.03225	118.85610
25	0.02849	92.59158

Table 4.31

Pattern 4. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 2 Percent Error.

Element Number	A_i	α_i
1	0.98007	76.53615
2	0.56469	82.05467
3	0.12249	41.43098
4	0.13759	-68.85524
5	0.10301	-107.55000
6	0.57770	91.33815
7	0.36819	67.04164
8	0.25021	-0.98577
9	0.20040	-32.24942
10	0.12219	-82.19569
11	-0.01582	-181.36070
12	0.15954	-8.04643
13	0.24185	12.72942
14	0.17916	-6.47224
15	0.06634	-5.18616
16	0.13652	-106.39890
17	0.08665	-37.85950
18	0.18658	-14.00842
19	0.16043	-5.82033
20	0.03897	-17.54759
21	0.10695	-93.15073
22	0.05579	-82.00270
23	0.01564	-47.20738
24	0.04218	122.42490
25	0.03842	96.16039

Table 4.32

Pattern 4. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 1 Percent Error.

Element Number	A_i	α_i
1	1.00995	87.30200
2	0.57462	71.41594
3	0.13242	37.85910
4	0.16751	-58.21365
5	0.11086	-103.97980
6	0.56778	87.76935
7	0.33828	56.28613
8	0.22031	9.77551
9	0.19048	-21.48825
10	0.11227	-80.95758
11	0.01409	-178.35520
12	0.15118	-4.47435
13	0.25178	9.15739
14	0.20907	-10.04464
15	0.07627	-15.94782
16	0.16644	-102.82870
17	0.11651	-48.62131
18	0.15668	-10.43635
19	0.15050	4.94060
20	0.00906	-13.97578
21	0.09703	-103.83660
22	0.02588	-82.34772
23	0.04555	-43.63550
24	0.03225	118.83660
25	0.00851	92.59158

Table 4.33

Pattern 4. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 2 Percent Error.

Element Number	A_i	α_i
1	1.01985	90.87250
2	0.56469	67.72171
3	0.12249	41.43115
4	0.17743	-54.52652
5	0.12078	-107.55110
6	0.57770	61.33984
7	0.32835	52.71344
8	0.21038	13.34765
9	0.20040	-17.91579
10	0.12219	-84.52890
11	0.02401	-177.61450
12	0.16111	-8.04650
13	0.24185	12.72952
14	0.21899	-11.57497
15	0.06634	-19.51967
16	0.17636	-106.40000
17	0.12637	-52.19350
18	0.14675	-14.00849
19	0.16043	7.43505
20	-0.00087	-11.92710
21	0.10696	-105.17790
22	0.03318	-85.91902
23	0.05548	-47.20755
24	0.04218	122.38420
25	-0.00141	91.33383

TABLE 4.34

Pattern 5. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 1 Percent Error.

Element Number	A_i	α_i
1	0.65060	99.26013
2	0.37304	106.42760
3	0.00745	101.81600
4	0.08857	-82.23674
5	0.08640	-45.24315
6	1.00998	38.29744
7	0.66055	33.42734
8	0.18020	34.65767
9	0.07037	-89.73033
10	0.13958	-143.54060
11	0.82609	6.09347
12	0.48946	4.94162
13	0.18212	-16.82225
14	0.06276	-164.23010
15	0.05580	-161.97100
16	0.52866	-71.47241
17	0.37535	-74.10629
18	0.11292	-89.93283
19	0.01421	59.96715
20	0.09094	65.32414
21	0.26640	-97.65575
22	0.16686	-103.73350
23	0.04862	-91.10423
24	0.06307	39.77171
25	0.04109	50.08115

TABLE 4.35

Pattern 5. Amplitude and Phase settings.

Maximum Impact on the Main Beam. 2 Percent Error.

Element Number	A_i	α_i
1	0.64067	95.68428
2	0.36311	102.85170
3	-0.00248	103.27540
4	0.07864	-78.66121
5	0.09632	-41.67044
6	1.01987	34.72470
7	0.67048	29.85460
8	0.19013	31.08493
9	0.06044	-86.15480
10	0.12964	-139.96510
11	0.83602	9.66548
12	0.49939	8.51364
13	0.19205	-13.24991
14	0.05283	-160.64750
15	0.04587	-158.39550
16	0.51873	-67.89690
17	0.34742	-70.53078
18	0.10299	-86.35732
19	0.02414	56.39423
20	0.10087	61.74829
21	0.25647	-94.08023
22	0.15693	-100.15800
23	0.03870	-87.52872
24	0.07300	36.19897
25	0.05101	46.50844

TABLE 4.36

Pattern 5. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 1 Percent Error.

Element Number	A_i	α_i
1	0.67058	99.37532
2	0.39302	106.54280
3	0.02743	108.96940
4	0.10855	-89.40341
5	0.08640	-52.43205
6	0.99001	38.29704
7	0.64057	33.46292
8	0.16022	41.81230
9	0.07037	-96.91640
10	0.15956	-150.72670
11	0.82609	6.09326
12	0.48946	4.94142
13	0.18212	-16.82198
14	0.06276	-164.31280
15	0.07572	-162.08570
16	0.54864	-78.65848
17	0.37733	-81.29237
18	0.13289	-97.11890
19	-0.00577	59.99971
20	0.09094	72.51126
21	0.26640	-97.77045
22	0.16685	-103.84820
23	0.04862	-91.21893
24	0.06307	39.77130
25	0.02111	50.08075

TABLE 4.37

Pattern 5. Amplitude and Phase settings.

Maximum Impact on Side Lobe 1. 2 Percent Error.

Element Number	A_i	α_i
1	0.68051	106.09150
2	0.40294	113.25900
3	0.03736	110.26660
4	0.11847	-92.95166
5	0.07910	-56.00414
6	0.98007	34.72459
7	0.63064	29.85451
8	0.15029	43.11046
9	0.07766	-100.48820
10	0.16948	-154.29850
11	0.83602	9.66543
12	0.49939	8.51360
13	0.17931	-13.24987
14	0.07365	-160.62240
15	0.08558	-158.39530
16	0.55856	-82.23029
17	0.38725	-84.86417
18	0.14282	-100.69070
19	-0.01570	58.69946
20	0.10086	76.08180
21	0.25647	-94.08002
22	0.15692	-100.15770
23	0.03870	-87.52849
24	0.07300	44.78825
25	0.01378	46.98734

TABLE 4.38

Pattern 5. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 1 Percent Error.

Element Number	A_i	α_i
1	0.65060	106.44720
2	0.39302	113.61470
3	0.00745	101.93120
4	0.10855	-89.42329
5	0.06642	-45.24286
6	1.00995	45.48639
7	0.64057	33.42696
8	0.16022	41.84660
9	0.07037	-89.84552
10	0.15956	-143.65580
11	0.80611	-1.09571
12	0.48946	4.94144
13	0.16214	-24.01114
14	0.06276	-171.38470
15	0.07578	-165.52790
16	0.54864	-78.65897
17	0.35735	-81.29286
18	0.13290	-90.04802
19	-0.00577	60.04353
20	0.09094	72.43388
21	0.26640	-104.84230
22	0.18683	-110.92000
23	0.04862	-91.21942
24	0.04309	46.96063
25	0.03351	50.08078

TABLE 4.39

Pattern 5. Amplitude and Phase settings.

Maximum Impact on Side Lobe 2. 2 Percent Error.

Element Number	A_i	α_i
1	0.64067	110.01770
2	0.40294	117.18520
3	-0.00248	104.43720
4	0.11847	-92.99461
5	0.05649	-41.67038
6	1.00713	49.05843
7	0.63064	29.85451
8	0.15029	45.41866
9	0.06044	-86.15459
10	0.16948	-139.96490
11	0.79618	-4.66772
12	0.49939	8.51360
13	0.15221	-27.58324
14	0.05283	-174.95600
15	0.08570	-162.32360
16	0.55856	-82.23029
17	0.34742	-84.86417
18	0.14282	-86.35709
19	-0.01570	58.69946
20	0.10086	73.77478
21	0.25647	-108.41360
22	0.19676	-114.49130
23	0.03870	-87.52849
24	0.03317	50.53267
25	0.01147	46.50833

Table 4.40. Summary of A_i, α_i Impact Data.

Pattern	Error	Main Beam		Side Lobe 1		Side Lobe 2		Null	
		$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX
1	1%	0.87	1.0	4.80	5.0	5.10	6.0	29.00	29.0
	2%	0.91	2.0	7.90	8.0	5.60	9.0	34.0	34.0
2	1%	0.92	1.0	7.78	9.0	5.51	6.0		
	2%	1.15	1.0	11.78	13.0	9.12	11.0		
3	1%	0.92	1.0	8.36	8.0	6.00	4.0	24.80	21.0
	2%	1.10	1.0	11.64	12.0	10.36	9.0	29.60	26.0
4	1%	0.81	1.0	7.10	8.0	7.27	9.0		
	2%	1.81	2.0	10.50	12.0	11.64	14.0		
5	1%	0.97	1.0	10.85	11.0	7.53	5.0		
	2%	1.97	2.0	15.50	16.0	11.02	9.0		

$\Delta\overline{G}$, ΔGMAX in dB.

Table 4.41. Summary of Aggregated Side Lobe Impact Data.

Pattern	1%		2%	
	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX
1	4.95	5.50	6.75	8.50
2	6.65	7.50	10.45	12.00
3	7.18	6.00	11.00	10.50
4	7.23	8.50	11.07	13.00
5	9.19	8.0	13.56	12.5

$\Delta\overline{G}$, ΔGMAX in dB.

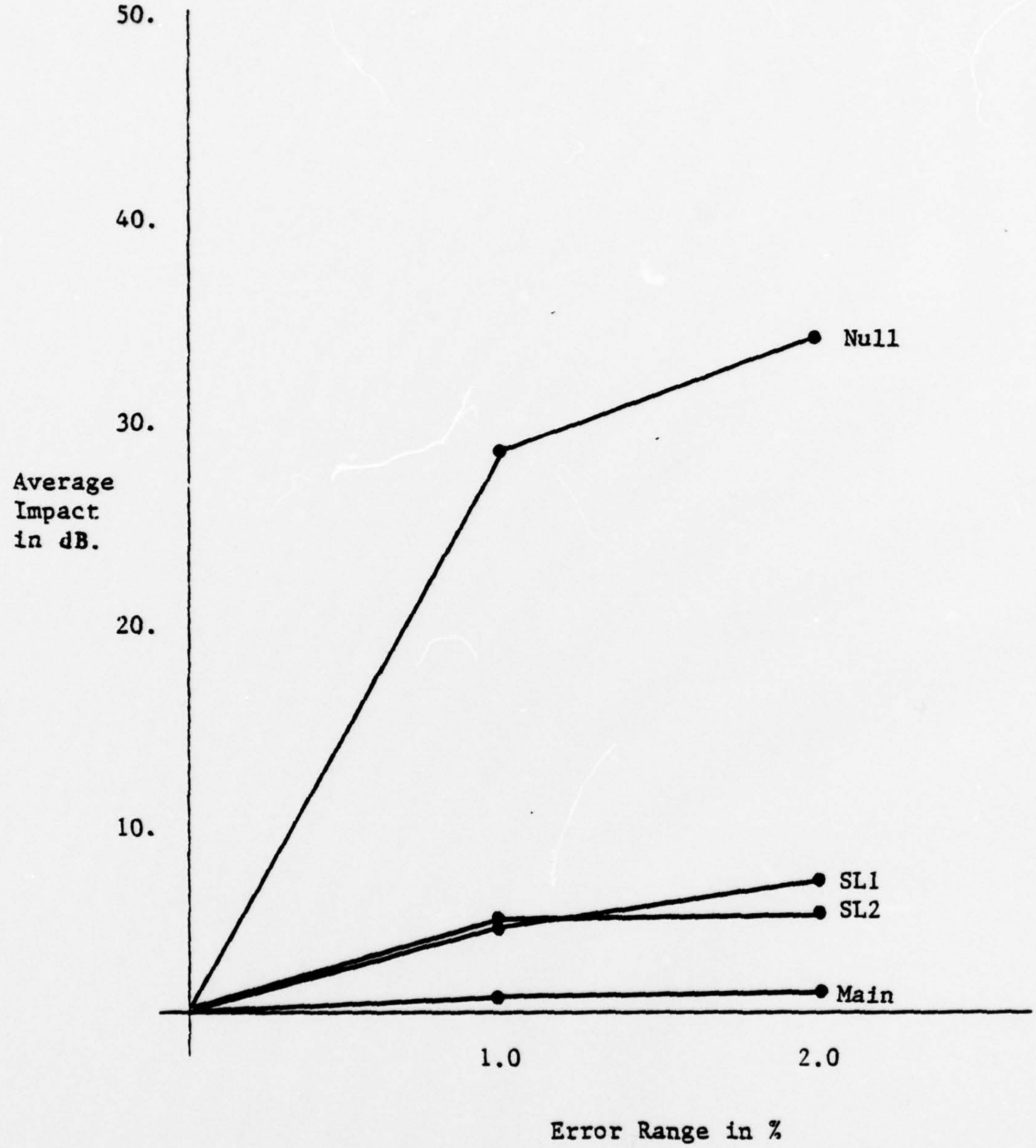


Figure 4.46
Pattern 1
$\overline{\Delta G}$ vs. Error Range by Feature.

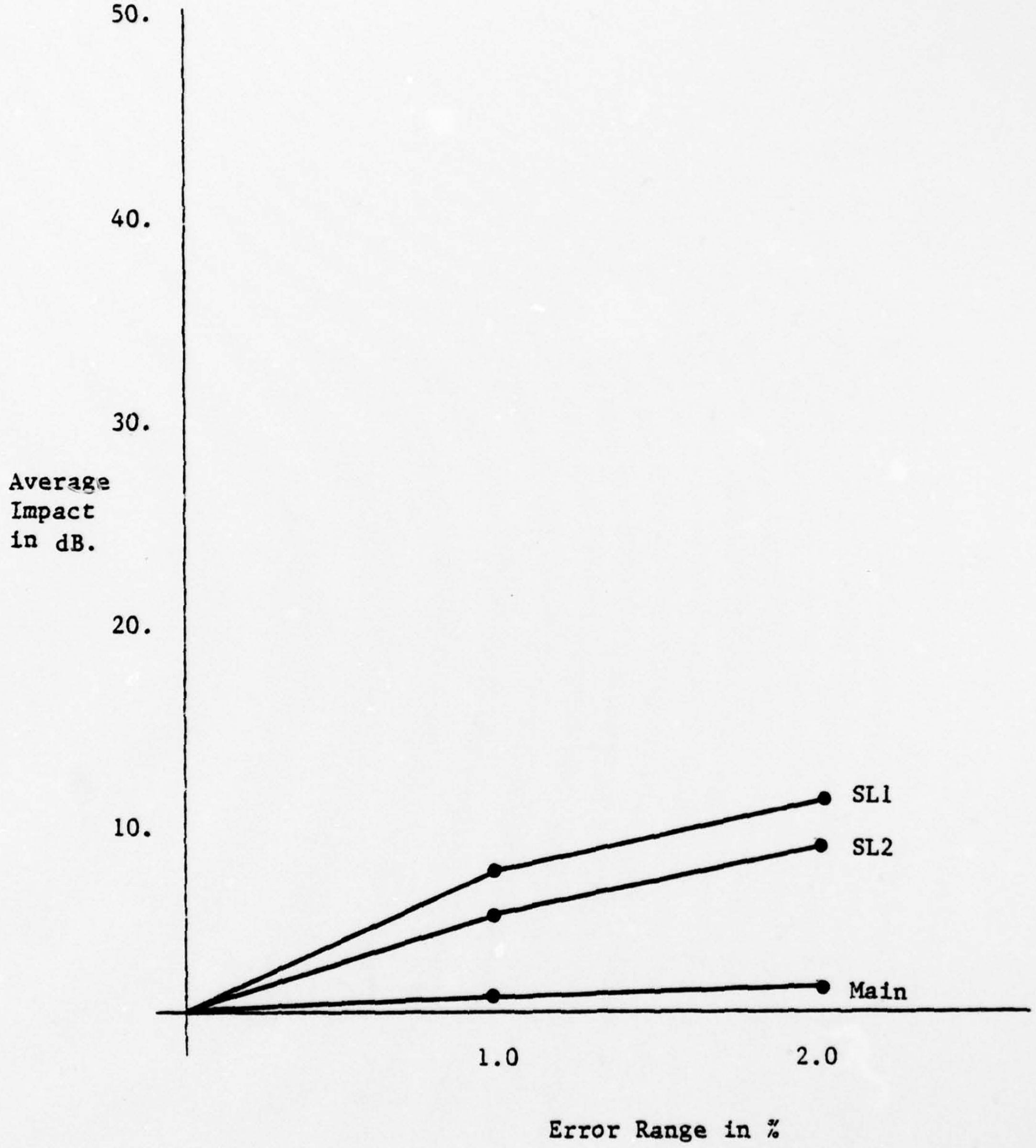


Figure 4.47
Pattern 2
$\overline{\Delta G}$ vs. Error Range by Feature.

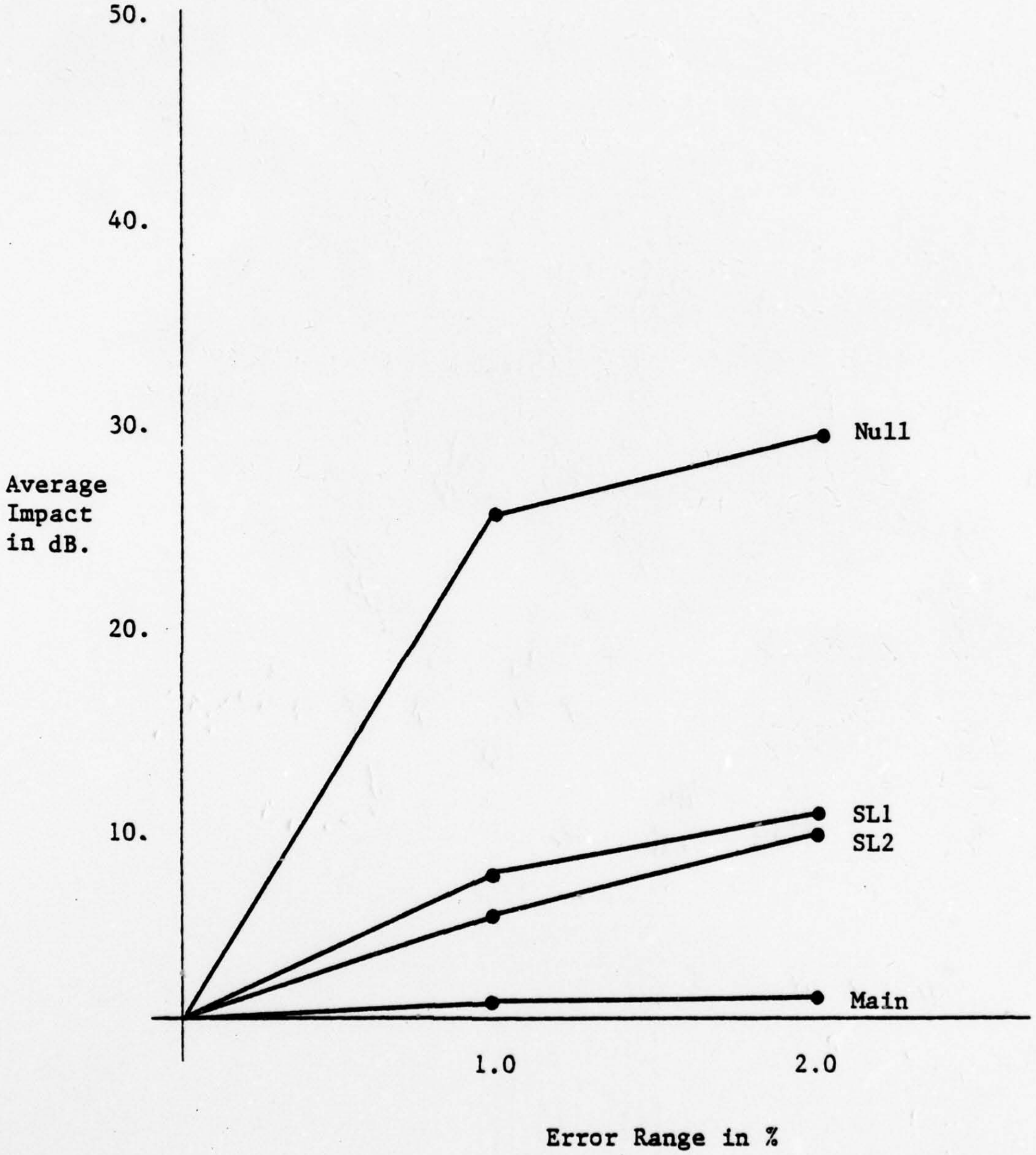


Figure 4.48
Pattern 3
$\overline{\Delta G}$ vs. Error Range by Feature.

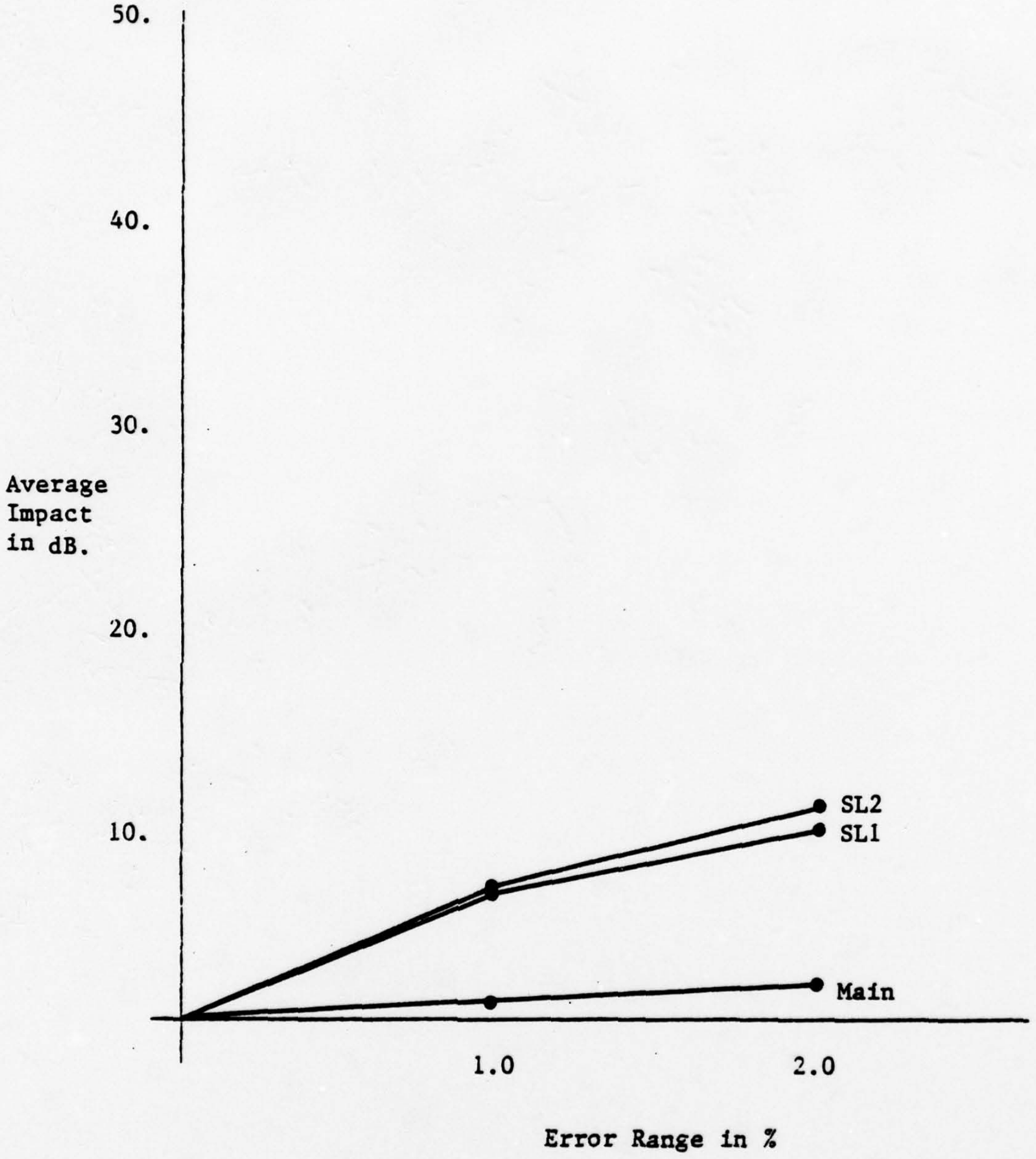


Figure 4.49
Pattern 4
$\overline{\Delta G}$ vs. Error Range by Feature.

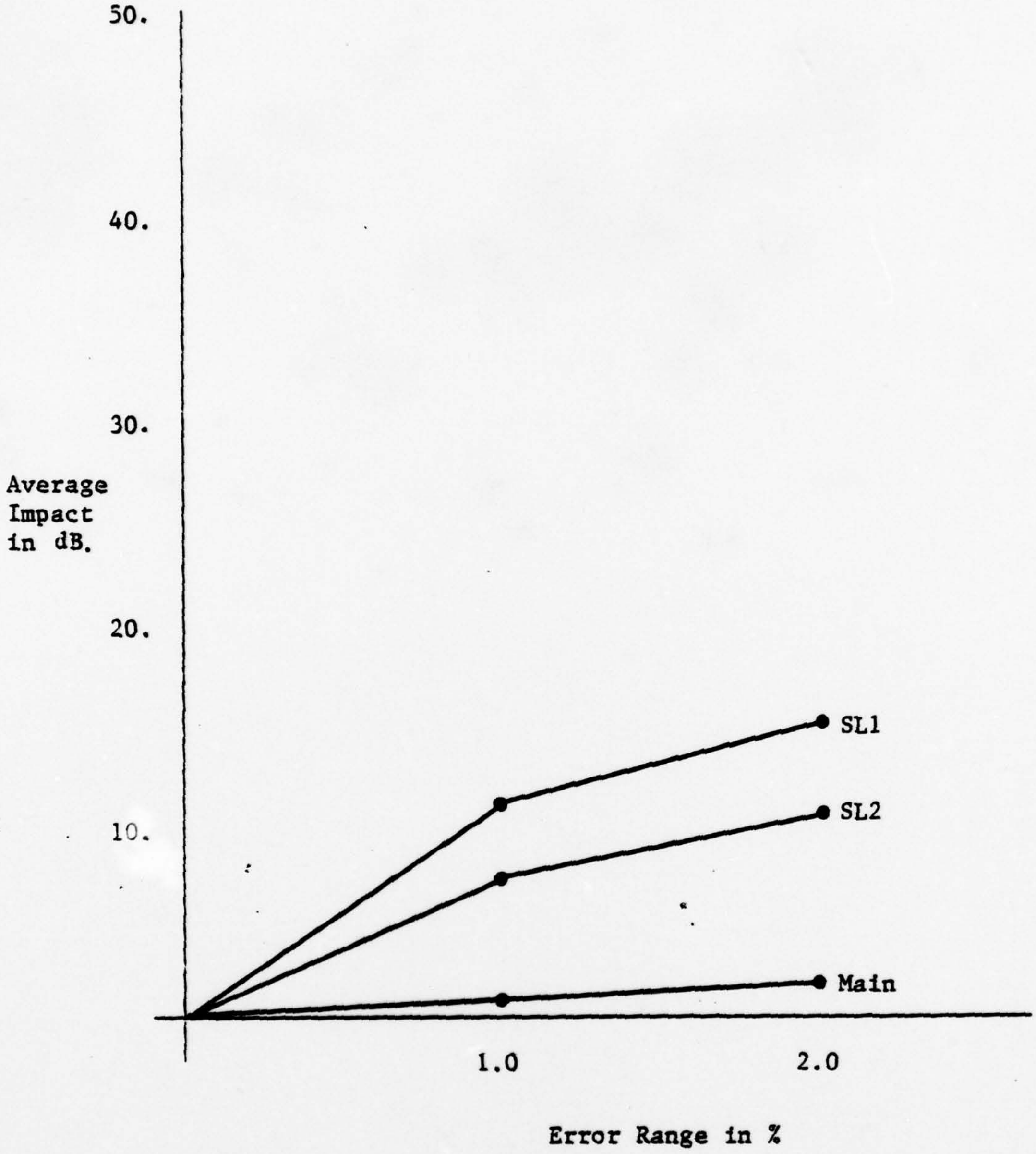


Figure 4.50
Pattern 5
$\overline{\Delta G}$ vs. Error Range by Feature.

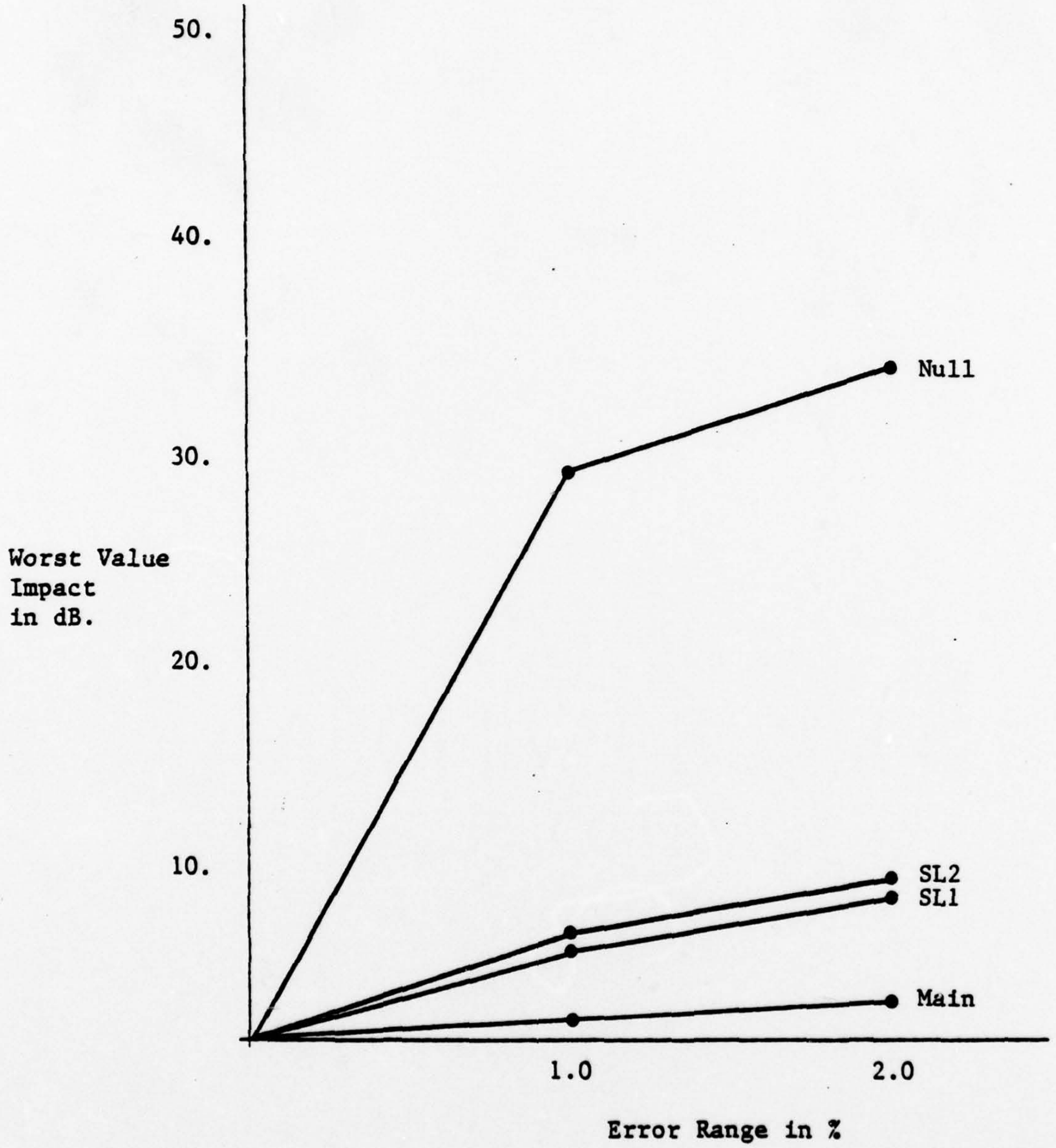


Figure 4.51
Pattern 1
Δ Gmax vs. Error Range by Feature.

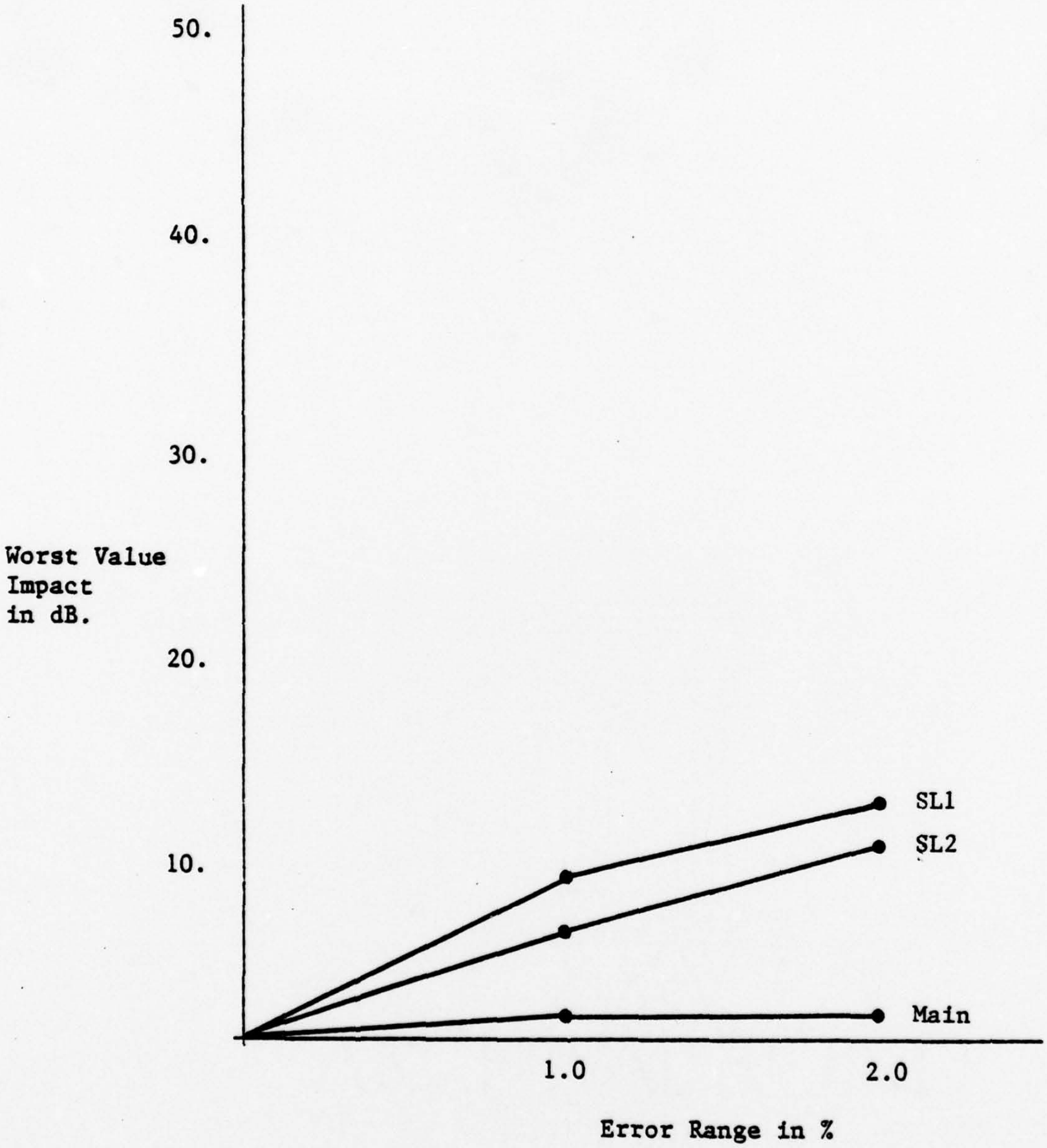


Figure 4.52
Pattern 2
ΔGmax vs. Error Range by Feature.

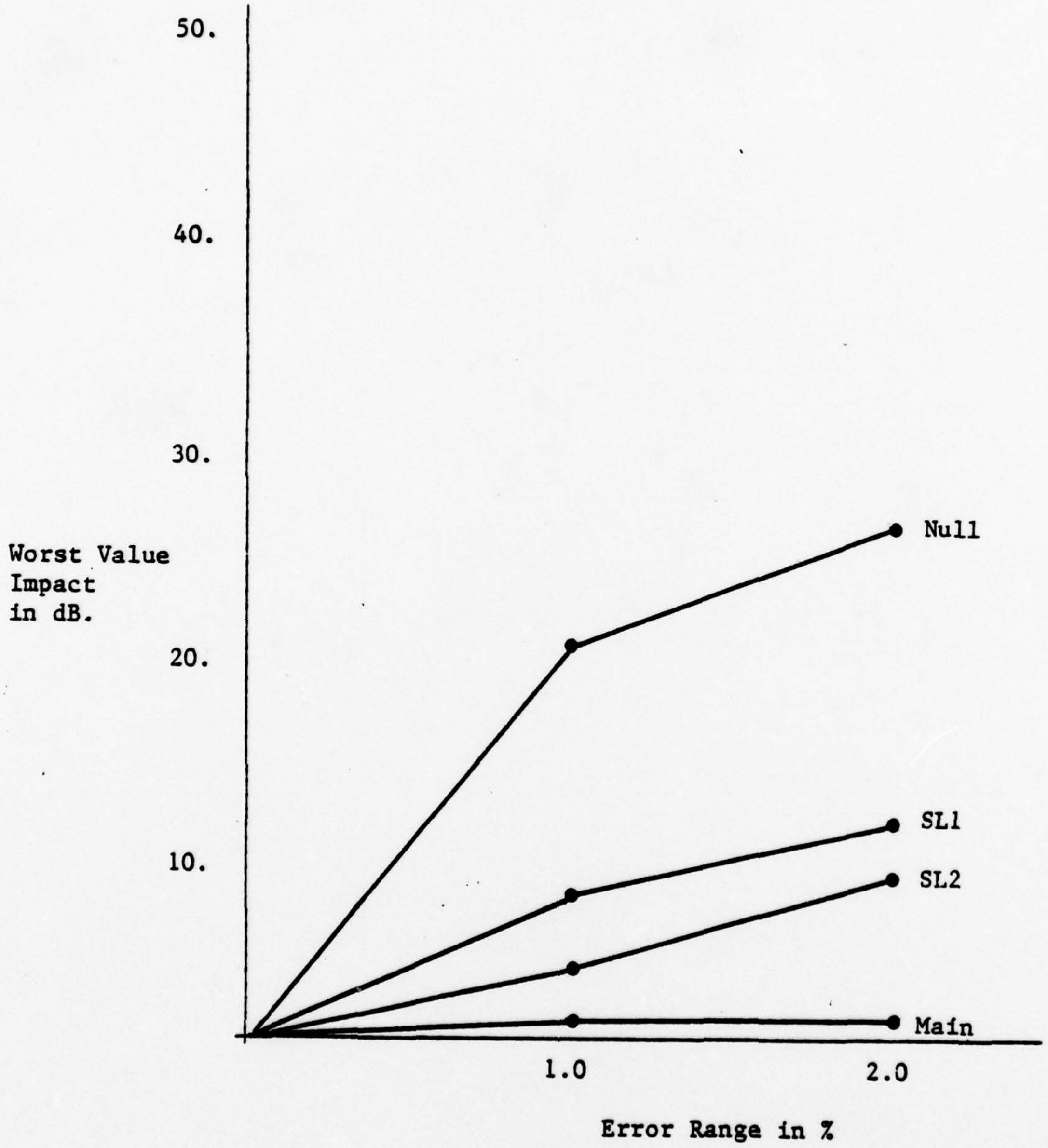


Figure 4.53
Pattern 3
Δ Gmax vs, Error Range by Feature.

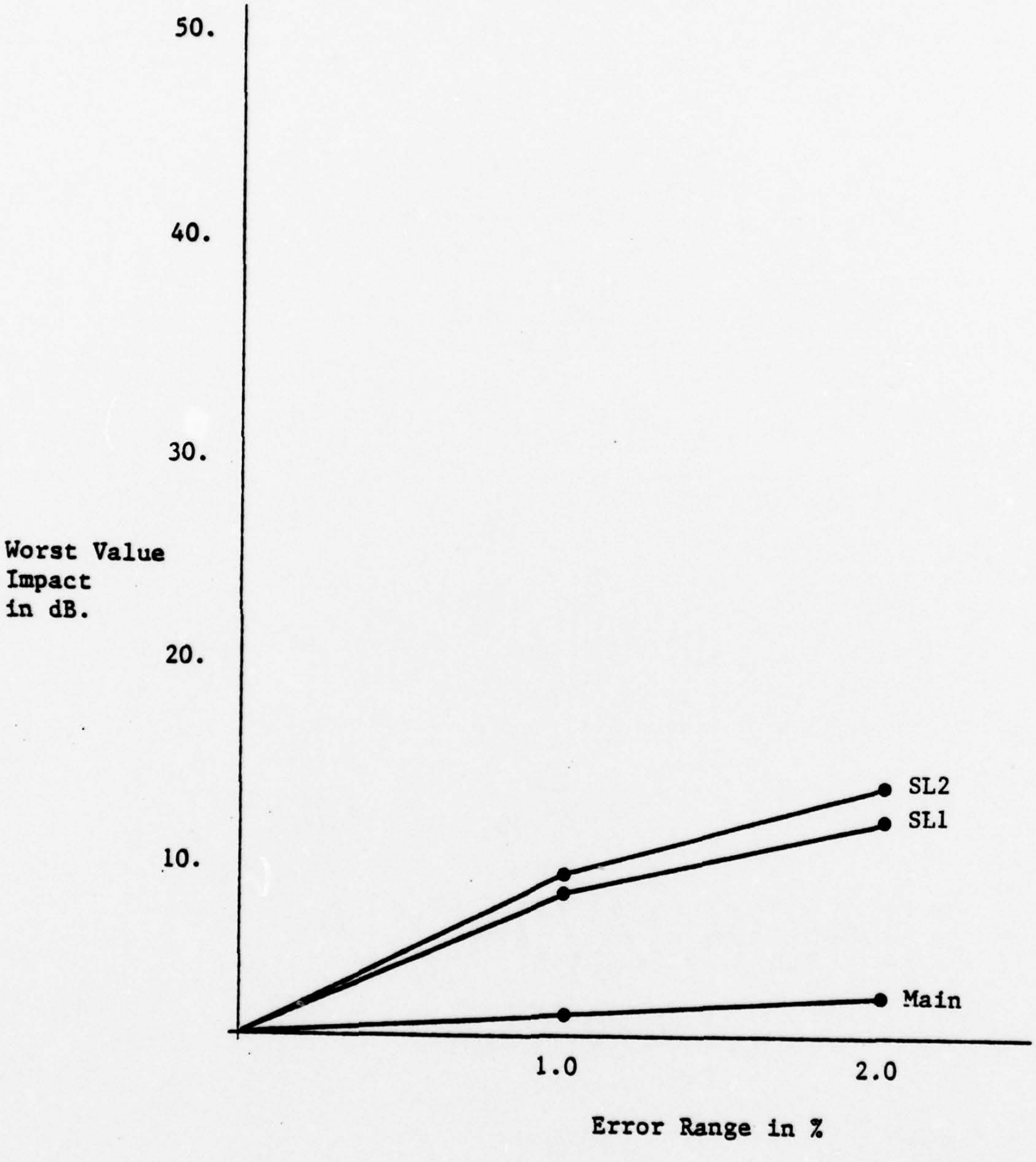


Figure 4.54
Pattern 4
Δ Gmax vs. Error Range by Feature.

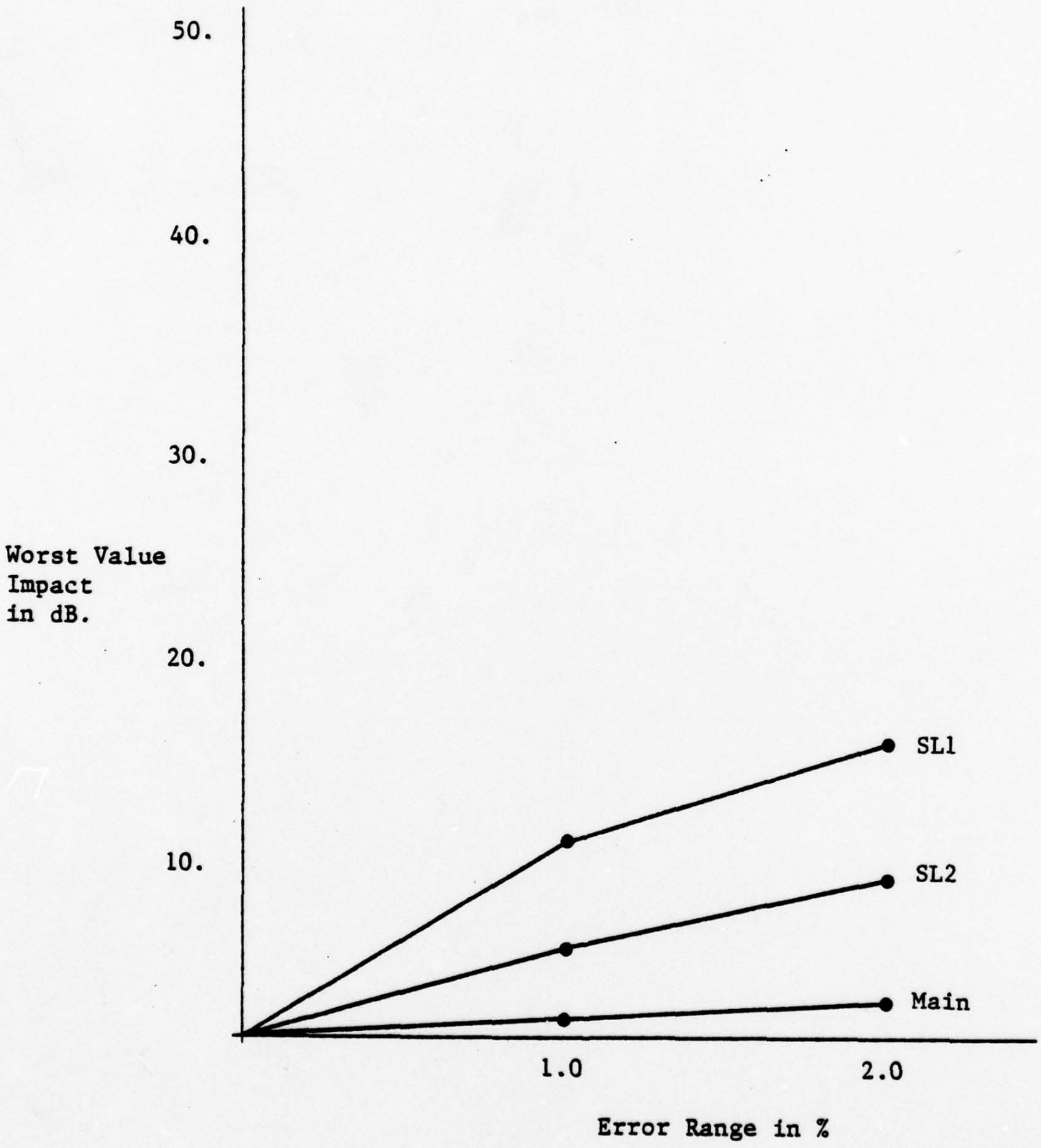


Figure 4.55
Pattern 5
ΔGmax vs. Error Range by Feature.

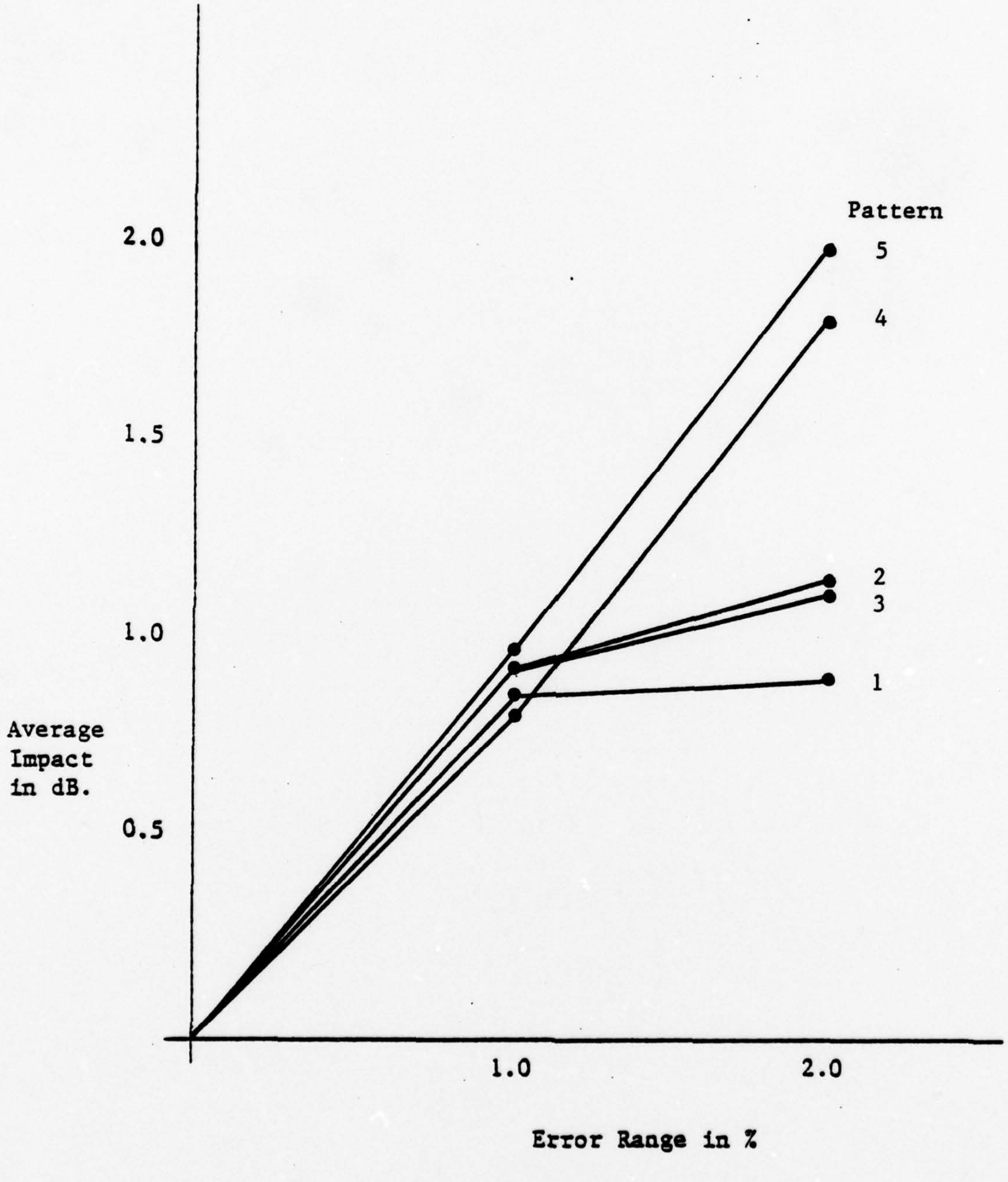


Figure 4.56
Main Beam Impact
$\overline{\Delta G}$ vs. Error Range by Pattern.

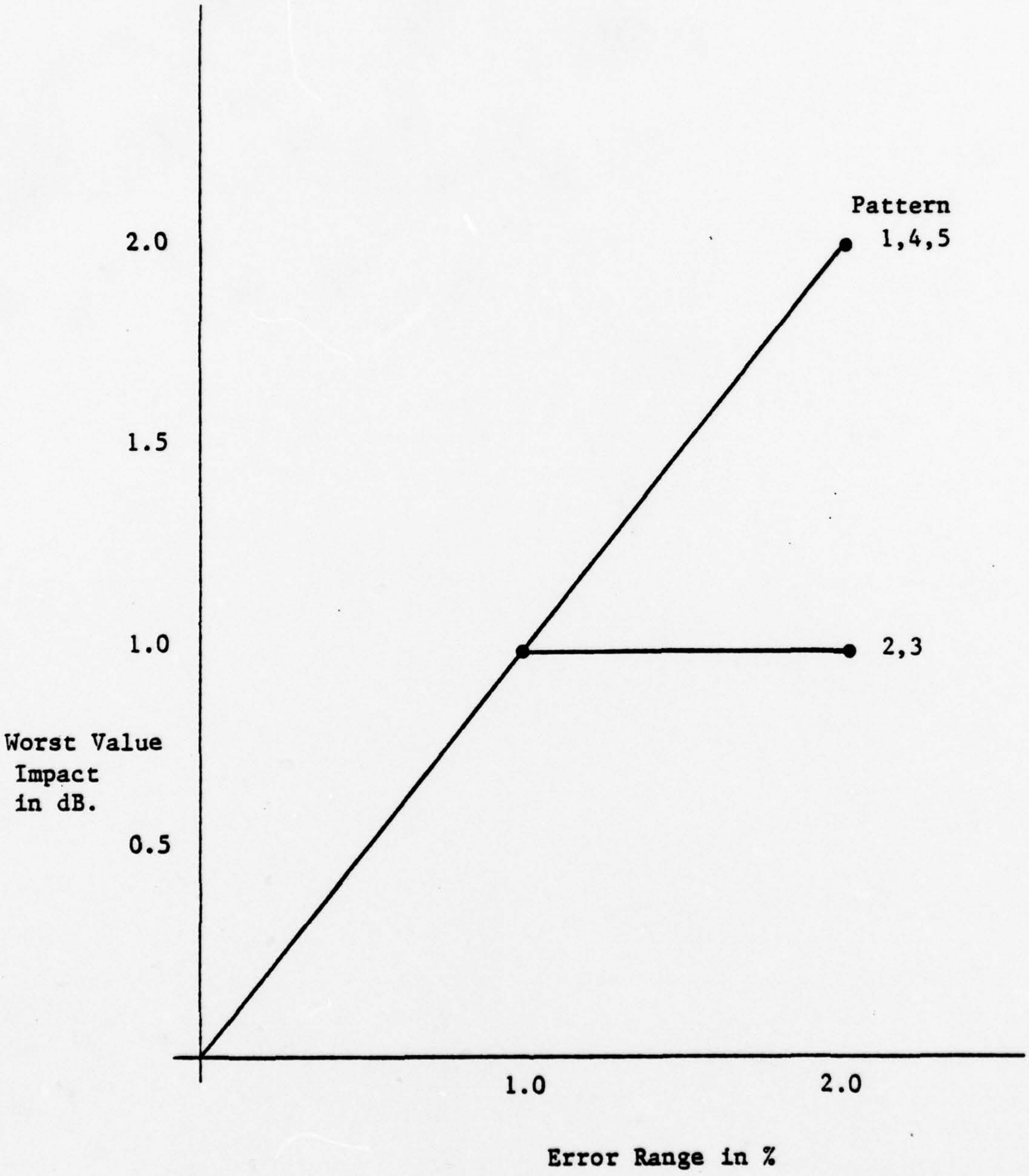


Figure 4.57
Main Beam Impact
Δ Gmax vs. Error Range by Pattern.

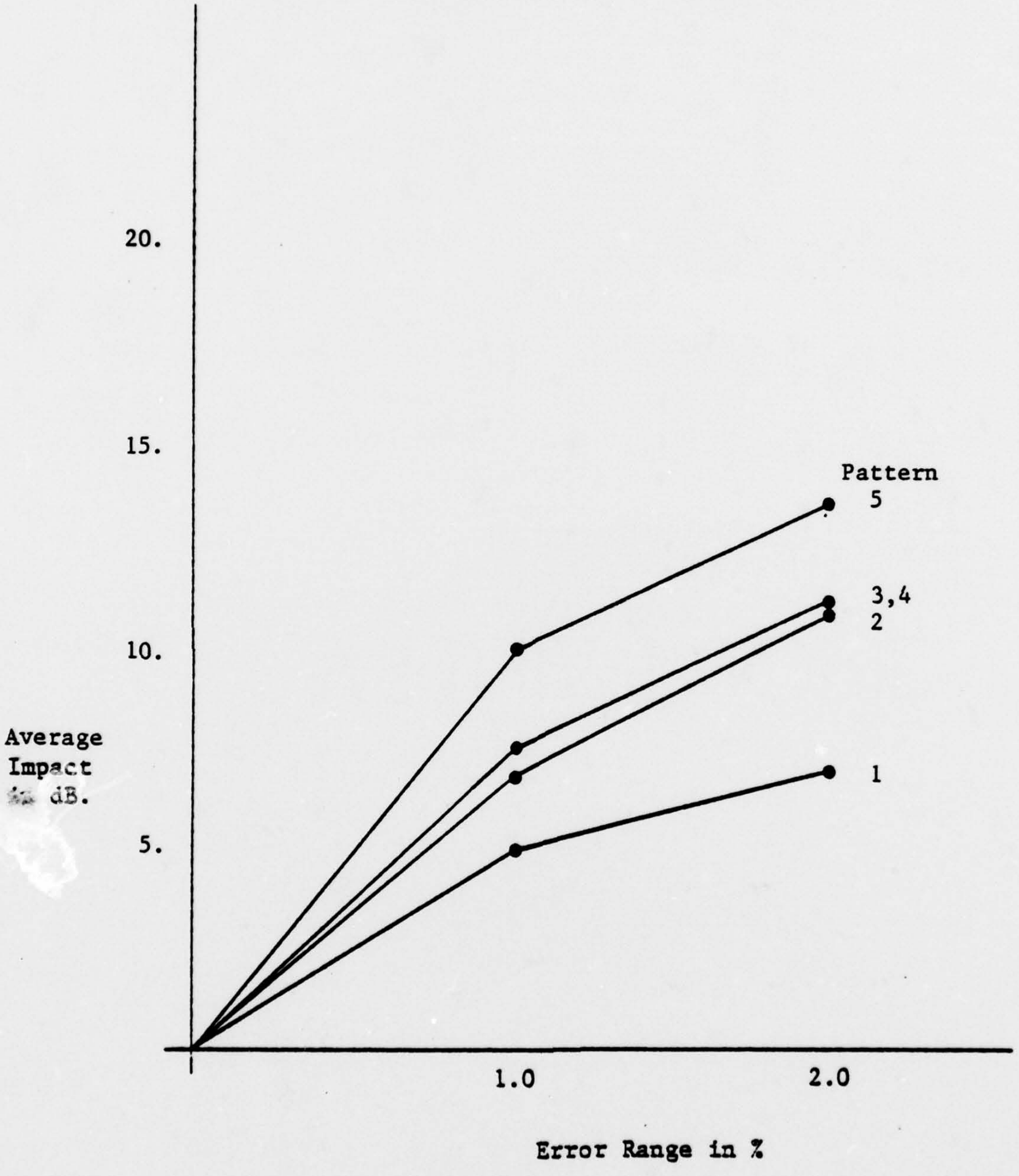


Figure 4.58
Aggregated Side Lobe Impact.
ΔG vs. Error Range by Pattern.

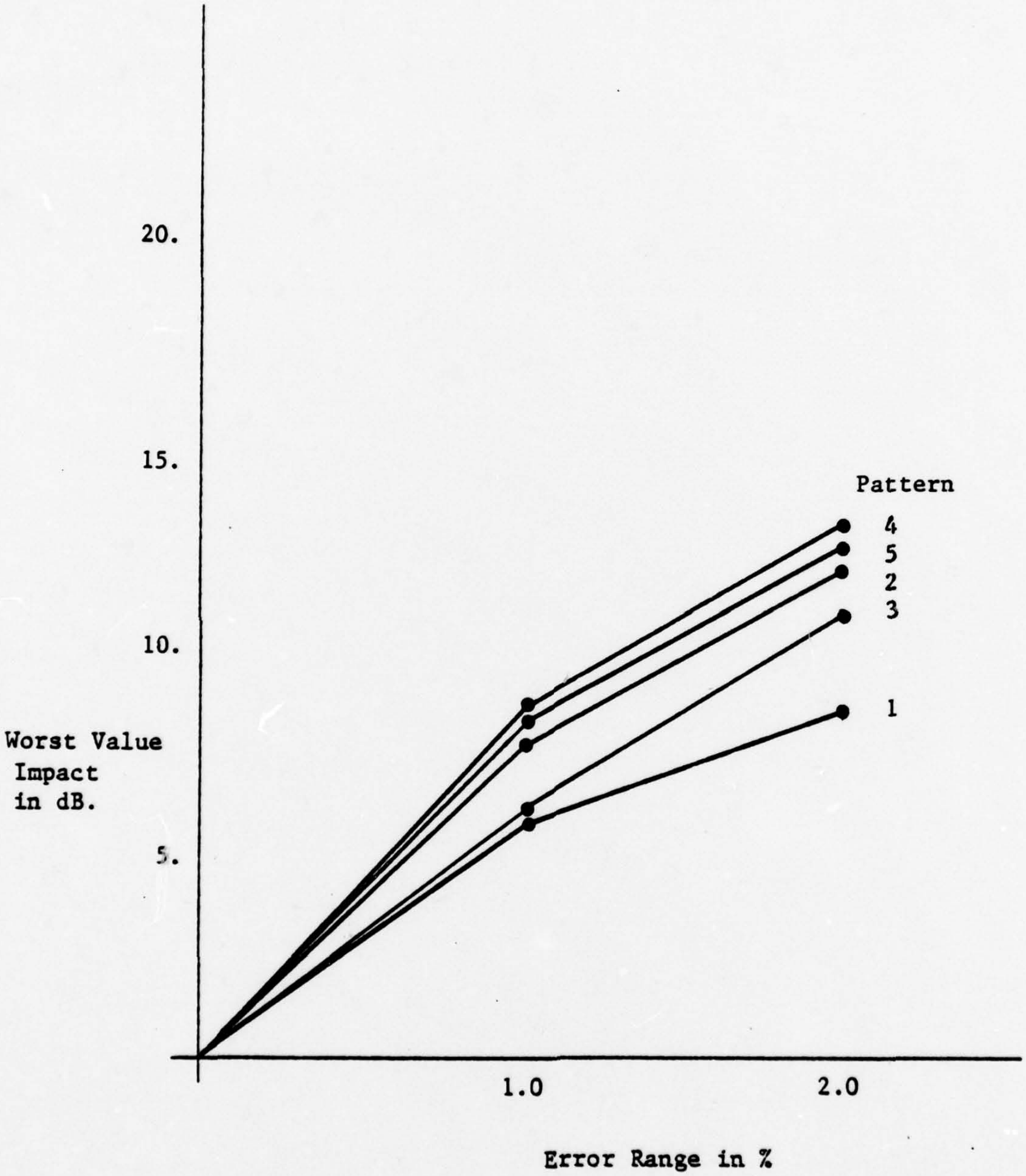


Figure 4.59
Aggregated Side Lobe Impact.
Δ Gmax vs. Error Range by Pattern.

Table 4.42. Summary of λ Error Impact Data.

Pattern	λ	Main Beam		Side Lobe 1		Side Lobe 2		Null	
		$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX
1	.98	0.333	1.0	-0.571	0.0	0.0	1.0	-1.0	-1.0
	.99	0.110	0.0	-0.214	0.0	0.167	1.0	0.0	0.0
	1.01	0.0	0.0	0.357	0.0	0.333	1.0	1.0	1.0
	1.02	0.0	0.0	0.143	-1.0	0.500	1.0	3.0	3.0
2	.98	0.077	0.0	-0.667	0.0	0.462	0.0		
	.99	0.0	0.0	-0.222	0.0	0.346	0.0		
	1.01	0.0	0.0	0.0	0.0	-0.308	0.0		
	1.02	0.0	0.0	-0.222	0.2	0.577	0.0		
3	.98	0.077	0.0	-0.727	0.0	-0.111	-1.0	-1.0	-1.0
	.99	0.077	0.0	-0.182	0.0	0.0	-1.0	-1.6	-3.0
	1.01	0.0	0.0	-0.454	0.0	-0.111	0.0	-0.6	0.0
	1.00	0.0	0.0	-0.273	0.0	-0.222	0.0	-0.2	1.0

Table 4.42 (continued).

		Main Beam		Side Lobe 1		Side Lobe 2		Null	
Pattern	λ	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX	$\Delta\overline{G}$	ΔGMAX
4	.98	0.187	1.0	-0.737	-1.0	-0.187	-1.0		
	.99	0.0	0.0	-0.818	-2.0	0.187	-1.0		
	1.01	-0.134	0.0	-0.818	-1.0	0.50	-1.0		
	1.02	-0.20	0.0	-0.737	-1.0	0.50	-1.0		
5	.98	0.158	1.0	-0.128	0.0	0.815	1.0		
	.99	0.031	0.0	-0.428	0.0	0.259	1.0		
	1.01	0.031	0.0	0.214	1.0	-0.593	0.0		
	1.02	-0.094	-1.0	0.143	0.0	-1.185	-1.0		

$\Delta\overline{G}$, ΔGMAX in dB.

CHAPTER V

DISCUSSION OF THE RESULTS
AND EXTENSIONS OF THE METHOD

5.1 Implications of the results

The analysis presented is meant to illustrate the power of the MAXIM-IOS method, and not to generate sensitivity data for a particular design problem. None the less, some trends which may be tentatively identified in the data deserve comment.

1. The nulls appear as the most sensitive feature in the pattern by a factor of about three over the side lobes.
2. Among the features examined, the main beams showed the least sensitivity overall. However, among the main beams, the square or rectangular shapes were much more sensitive at the 2 percent error range than the round beam.
3. In general, the broader the main beam, the greater the side lobe sensitivity appeared to be.
4. The minimum elevation points on the error surface almost universally occurred at the edge of the error interval of each decision variable.

The first three observations accord well with intuitive expectations for feature sensitivity. The fourth observation is

exactly what would be expected for a well behaved error surface. That is, the error regions appear to be tightly enough constrained about an optimum to contain only one local minimum. It is to be expected that such a minimum will lie on an edge, as far from the maximum as possible. Thus it can be said that for a 10 by 10 array at least, MAXIM-generated sensitivity values can be accepted with some confidence within the two percent error region.

5.2 Potential uses for MAXIM

The worst performance possible for an array design or feature, deriving from error is, in itself, a valuable piece of information. However, MAXIM can be used to generate other types of information as well. In Chapter four, only one type of experiment which may be designed around MAXIM was described. There, a method to determine the relationship between directivity pattern and sensitivity was examined. If such an experiment were to be performed on a series of alternative pattern designs, the procedure could be refined somewhat. Presumably, the alternatives to be evaluated in an actual application are not likely to differ from each other as radically as the sample in the above study. The sensitivity of a pattern might, for instance, be examined as one feature in a pattern changes over some interval. It may prove that in some cases, it is possible to greatly decrease sensitivity through small modifications in the design specifications. It should be noticed that in such a case the IOS will tend to be based on a meaningful set of standards.

It would also be of value to take MAXIM values on a finer set of error ranges than those used in this study. The relative rate of change

in maximum degradation of given features over an error range is of importance, since it can give an indication of the expected degradation. For instance, suppose two features were to be compared for sensitivity, and the following MAXIM data were obtained. At one percent error the first feature had a sensitivity value of 5 dB, while the second had a sensitivity value of 10 dB. At two percent error the sensitivity value of both features was 15 dB. In this case, the expected performance of the first feature would be worse than the second.

Element amplitude and phase coefficient error ranges could be analyzed separately, allowing these ranges to take on realistic values for the particular system being studied.

If, in a given application, array pattern sensitivity is to be taken into account at the design stage, it is possible, by holding any two of the following three array characteristics constant, to perform a sensitivity analysis similar to the one in this study on the third.

1. Array size and geometry.
2. Directivity pattern design.
3. Error ranges.

Number three assumes the existence of a reliable means of converting the effects of error sources, such as those mentioned in Chapter two, into error ranges in A_i and α_i and conversely. Then, sensitivity value vs. error range graphs, such as figure 4.56 could be used to specify acceptable tolerances for array or component manufacture.

Finally, the arrays examined in this study have all been of the planar symmetric type. MAXIM may easily be extended to the more general case of conformal array sensitivity analysis, since NLGP Conformal, a non-linear goal programming code specifically for the conformal array

case, has already been developed. A modification of this code to yield a conformal version of MAXIM would also make it possible to analyze non-symmetric error in planar symmetric arrays.

5.3 Summary

The MAXIM-IOS method of sensitivity/impact analysis has been presented and illustrated with a sample study on five rather complex array patterns. The resulting measure, maximum impact, represents the worst realization which a particular feature of a pattern can assume due to a given amount of error. The change in the value of this realization as error in amplitude and phase settings increases is also an indicator of the shape of the response surfance in the error region.

Since MAXIM is based on an optimization technique, this kind of sensitivity analysis may be completed at a very small cost in computation time. It will now be practical, therefore, to include the results of MAXIM-IOS analyses of specific proposed arrays and array patterns as a factor to be taken into account during the design process.

Maxim compares well with simulation-based sensitivity analysis. Although at first glance the sensitivity measures which can be estimated through simulation seem to give more information, these values are in fact dependent on a priori assumptions concerning error distribution. MAXIM, on the other hand, requires no such assumptions. The cost factor, however, is the chief advantage of MAXIM over simulation. This advantage becomes steadily more pronounced as array size increases.

APPENDIX A

THE DIRECTIVITY FUNCTION FOR A PLANAR SYMMETRIC ARRAY

A.1 Derivation From the General Case

For a planar array in the X-Z plane consisting of n elements, the magnitude of the contribution to the directivity pattern, at an aspect angle of θ, ϕ, of an element located at x_i, z_i is:

$$A_i \exp[j(u_i + \alpha_i)] \qquad (A.1)$$

where:

$u_i = kx_i \sin\theta\cos\phi + kz_i \cos\theta$

A_i is the amplitude shading coefficient.

α_i is the phase shift.

$k = 2\pi/\lambda$

λ is the operating wavelength.

The combined output of n elements is given by:

$$A_i \exp[j(u_i + \alpha_i)] \qquad (A.2)$$

which is equal to

$$A_i(\cos \alpha_i + j \sin \alpha_i)(\cos u_i + j \sin u_i)$$

Consider the contributions from four elements, placed symmetrically about the center of the array at the points: (x_i,z_i), $(-x_i,z_i)$, $(-x_i,-z_i)$, and $(x_i,-z_i)$. Suppose further that these elements are excited identically (i.e., have identical A_i and α_i coefficients). This result is:

$$A_i(\cos \alpha_i + j \sin \alpha_i)[\cos u_1 + j \sin u_2 + \cos u_2 + j \sin u_1 + \cos(-u_1) + j \sin(-u_1) + \cos(-u_2) + j \sin(-u_2)] \tag{A.4}$$

where:

$$u_1 = kx_i \sin\theta \cos\phi + kz_i \cos\theta$$
$$u_2 = -kx_i \sin\theta \cos\phi + kz_i \cos\theta$$

Since, for any angle r, $\cos r = \cos(-r)$, and $\sin r = -\sin(-r)$, this becomes:

$$2A_i(\cos \alpha_i + j \sin \alpha_i)[\cos u_1 + \cos u_2] \tag{A.5}$$

By applying the double angle formula, equation A.5 can be stated as:

$$4A_i\ (\cos \alpha_i + j \sin \alpha_i) \cos(\kappa x_i \sin \theta \cos \phi) \cos(\kappa z_i \cos \theta) \tag{A.6}$$

Finally, the power response at θ,ϕ, for m sets of four elements is obtained by multiplying A.6 by its complex conjugate. Thus:

$$P_{\theta\phi} = 16[(\sum_{i=1}^{n} A_i \cos \alpha_i \cos(\kappa x_i \sin \theta \cos \phi) \cos(\kappa z_i \cos \theta))^2$$
$$+ (\sum_{i=1}^{n} A_i \sin \alpha_i \cos(\kappa x_i \sin \theta \cos \phi) \cos(\kappa z_i \cos \theta))^2] \quad (A.7)$$

The power response is to be expressed in dB. Therefore we write:

$$G_{(\theta,\phi)} = 10\log[P_{(\theta,\phi)}/P_{(0,0)}] \quad (A.8)$$

Where:

$P_{(0,0)}$ is the peak power output for the array in any direction.

APPENDIX B

THE HOOKE AND JEEVES PATTERN SEARCH ALGORITHM

B.1 Notation

Before describing the pattern search logic, it is necessary to define several parameters and notational conventions.

1. $\bar{a}$ is a vector of n decision variable values.
2. d_j is the perturbation step size for the j^{th} search iteration.
3. t_{jk} is the trial point obtained after perturbing about the k^{th}, (k=1,n), decision variable in the j^{th} search iteration.
4. α is the search acceleration factor.

B.2 Pattern Search Logic

The pattern search proceeds from an initial base point a, which then becomes the trial point for the first iteration when no variables have yet been perturbed, written t_{10}. Each variable is successively perturbed by $\pm d_1$. t_{10} and d_1 are user specified parameters. If t_{1k} is preferred over $t_{1(k-1)}$, the search will move to t_{1k} and perturb the $k+1^{th}$ variable. The algorithm evaluates trial points by simply substituting the associated decision variable values into the achievement function. After all n variables have been perturbed, t_{1n} is

compared to t_{10}. If t_{1n} is not preferred over t_{10}, the perturbation step size is reduced, and the variables are again perturbed about t_{10}. If, however, t_{1n} is preferred over t_{10}, the search proceeds to a new trial point, denoted t_{20} and given by:

$$t_{20} = (t_{1n} - t_{10}) \cdot \alpha$$

t_{20} is then compared to t_{1n}. If t_{20} is preferred over t_{1n}, the next iteration begins, from there. If not, then t_{1n} becomes t_{20}, d_2 is reduced to a fractional part of d_1, and the next iteration begins at that point.

The pattern search can terminate in the following ways:

1. A prespecfied maximum number of search iterations may be equalled.
2. A user defined maximum number of perturbation step size reductions may be reached.
3. The solution may be within some tolerance factor of the theoretically optimal point.
4. The improvement between two successive trial base points may be below a specified tolerance limit.

APPENDIX C

LINEAR TECHNIQUES

C.1 Properties of Linear Models

A linear optimization model has the following general form. An objective function

$$\sum_{i=1}^{m} d_i x_i$$

is to be maximized subject to n constraints:

$$\sum_{i=1}^{m} c_{ij}\, x_i \left(\substack{\leq \\ = \\ \geq}\right) b_j \qquad j=1,\ldots,n$$

where the x_i are decision variables, and the c_{ij} are numerical coefficients. If a non-linear optimization problem may be transformed into or approximated by a linear problem, it can be solved using linear programming techniques. Theoretically, the various linear programming algorithms always find the optimal solution(s) if they exist. However, in the case of large linear programming problems requiring the performance of a great many operations, round-off error accrued during the course of the calculations may lead to an invalid solution, or cause the algorithm to fail and find no solution at all.

It is possible, by manipulating the directivity function and aggregating variables, to achieve a linear formulation of array

directional response. The derivation of this result will be reviewed in this section, and the characteristics of the linear programming problems so obtained will be discussed.

C2. Linearization of the Directional Response Function

As shown in Appendix A, equation A.2, the combined output from n elements in a given direction, θ,ϕ, is given by:

$$P_{\theta\phi} = \sum_{i=1}^{n} A_i \exp[j(u_i + \alpha_i)]$$

where u_i depends on the operating wavelength, the element position, and the aspect angle. For an element in the X-Z plane, for instance,

$$u_i = \kappa x_i \sin\theta \cos\phi + \kappa z_i \cos\theta$$

The output expression may be equivalently written:

$$P_{\theta\phi} = \sum_{i=1}^{n} (\cos u_i + j \sin u_i)\, A_i\, (\cos \alpha_i + j \sin \alpha_i)$$

Expanding and rearranging terms gives:

$$P_{\theta\phi} = \sum_{i=1}^{n} [\cos u_i\, (A_i \cos \alpha_i) - \sin u_i\, (A_i \sin \alpha_i)] + j \sum_{i=1}^{n} [\cos u_i\, (A_i \sin \alpha_i) + \sin u_i\, (A_i \cos \alpha_i)]$$

If the terms $A_i \cos \alpha_i$ and $A_i \sin \alpha_i$ are understood to be decision variables (i.e., the shading coefficients are now complex), and the terms $\sin u_i$ and $\cos u_i$ to be coefficients, this function assumes the general linear form. The values taken on by the synthetic decision variables, $A_i \sin \alpha_i$ and $A_i \cos \alpha_i$, are not in themselves of interest. However, as long as both of them appear in the real component of the response function, it will be possible to recover the separate A_i and α_i

upon solution.

Since the coefficients $\cos u_i$ and $\sin u_i$ depend only on element positions and the Θ,ϕ points at which the pattern is to be evaluated, numerical values may be determined and substituted into the response function. Then the problem may be solved using any of a number of computer packages for linear probramming problems.

C3. Linear Models for General Arrays

In 1961, McMahon et al.[18] presented the transformation of the directivity function into a linear form, as reviewed above, and presented results for several linear and planar arrays in the 12 to 70 element range. This formulation applies to the most general case of array design. The array may be phased, and element positions may conform to any surface.

The chief disadvantage of this formulation is the size of the resultant linear programming problem. Four inequality constraints are required at each Θ,ϕ point defining the desired pattern in order to create upper and lower bounds on both the real and imaginary components of the response function. Furthermore, 4 non-negative decision variables are generated for each element of the array. Thus the size of the resultant linear programming problem is given by the polynomial, $Y = 4n \times 4m$, where n is the number of Θ,ϕ points needed to define the pattern, and m is the number of elements in the array. Adequate pattern definition will usually require upwards of 65 Θ,ϕ points per orthont. Thus, a conservative estimate for the linear programming problem generated by just a 100-element (conformal, planar, or linear) array, whose response is specified over a hemisphere, is 400 variables and

1,040 constraints.

Unfortunately, there is no direct relationship between the size of a linear programming problem and the complexity function of the algorithm required to solve it. It has, however, been the experience of the author that the use of this method to program arrays as small as 64 elements is prohibitively expensive.

The general array linear formulation suffers its severest shortcomings when applied to arrays whose elements are symmetrically placed. As shown in Appendix A for the planar array case, such symmetry conditions may be incorporated into the directional response function. This type of reformulation allows the pattern to be specified on a fractional part of the region over which it is to be defined. The number of θ,ϕ points needed to specify the pattern produced by an n element planar array displaying two-way symmetry is half that of a non-symmetric n-element array. Four-way symmetry halves this number again. Since each θ,ϕ point has 4 associated constraints, this method can greatly reduce problem size. However, as shown in equation A.5, the incorporation of symmetry conditions causes the $j\sin u_i$ terms to sum to 0 and drop out of the directivity function. The synthetic decision variables then become indeterminate in that unique values for A_i and α_i can no longer be recovered. Thus, the technique is incompatible with the linear formulation, and symmetric arrays will generate the same size problems as non-symmetric arrays. There is, however, one case where symmetry can reduce problem size for the linear formulation. When the array is planar-symmetric and relatively small $(n < m/2)$, the number of constraints will be reduced somewhat if directional response is specified in only one orthont, and the decision variables corresponding

to the elements in one quadrant of the array are set equal to those in the other three. For instance, if the 100-element array, 260 θ,ϕ point case given above is treated in this manner, the associated linear programming problem has 400 variables and 860 constraints.

C.4 The Planar-symmetric, Non-phased Case

Wilson [20] has presented results for planar arrays with two-way symmetry, and all element phase shift coefficients set to 0. In this case, the response at θ,ϕ from two elements placed symmetrically in the X-Z plane and excited identically is:

$$2A_i \cos u_i$$

where u_i is defined as above. This result can be extended to the four-way symmetry case, and becomes:

$$4A_i \cos u_i$$

Then the output of s sets of 4 symmetric elements is:

$$\sum_{i=1}^{s} 4A_i \cos u_i$$

This function contains no imaginary component, and since the decision variables, A_i, lie by definition between 0 and 1, only one decision variable is generated per set of 4 elements. The 100-element planar-symmetric, non-phased array with the same pattern as earlier examples, has an associated linear programming problem of 25 decision variables, and about 65 constraints. In general, the size of the problem in this case increases as the polynomial, n/4 x (m/4 + d/4) where d is the number of θ,ϕ points in the main beam.

The most general objective function for both McMahon's and Wilson's linear programming problems minimizes a weighted sum of deviations from the specified responses at the θ, ϕ points. Other objective funtions are possible, however. Wilson's formulation [20], for instance, minimizes the maximum deviation over the set of θ, ϕ points.

The recent development of a code to solve massive linear goal programming problems [17] allows the reformulation of these linear models as linear goal programming models. The multi-objective nature of array synthesis problems may now be represented in a preemptive priority structure, as well as in the relative weights assigned to the goals.

C.5 MAXIM for Planar Symmetric Non-Phased Arrays

It is only for the planar-symmetric non-phased array that the linear model has proved to be of practical value, since here the associated linear programming problems are of a size which is economically feasible. The same holds for MAXIM applications. The linear version of MAXIM is as follows:

$$\text{MIN } z = \sum_i w_i d_i$$

$$\text{St}: \sum_{j=1}^{n} \cos u_{ij} A_j + n_i - p_i = b_i$$

for the i θ, ϕ points in the feature under consideration. d is a negative deviation variable for the main beam, and a positive deviation variable elsewhere. The minimization takes place subject to a set of constraints given by:

$$\sum_{j=1}^{n} \cos u_{ij} A_j + n_i - p_i = b_i \qquad i=1,p$$

$$\left.\begin{aligned} A_j &\leq A_j^* + \varepsilon_j \\ A_j &\geq A_j^* - \varepsilon_j \end{aligned}\right\} \quad j=1,\ n/4$$

where A_i^* is the design soltion, and 2ε is the error range. The analysis then proceeds as with the non-linear model. All results established for the non-linear case hold here as well, with two exceptions. Only those error sources which are resolvable into error in amplitude settings may be treated with this formulation. Thus, for instance, error in element placement could not be analyzed. With regard to the solution technique itself, however, the optimal solution is now guaranteed.

BIBLIOGRAPHY

Books

1. Albers, Vernon M., Underwater Acoustics Handbook II. University Park, Pennsylvania, The Pennsylvania State University Press, 1965.

2. Beveridge, G. and Schechter, R. S., Optimization: Theory and Practice, New York, McGraw-Hill Book Co., 1970.

3. Ignizio, J. P. and Gupta, J.N.D., Operations Research in Decision Making, New York, Crane, Russak and Co., 1975.

4. Ignizio, J. P., Goal Programming and Extensions, Lexington, MA, D.C.Heath and Company, 1976.

5. Skolnik, Merril I., Introduction to Radar Systems, New York, McGraw-Hill Book Company, 1962.

6. Steinberg, Bernard D., Principles of Aperture and Array System Design, New York, John Wiley and Sons, 1976.

7. Wilde, D. J. and Bieghtler, C. S., Foundations of Optimization, Prentice-Hall Inc., Englewood Cliffs, NJ, 1967.

Articles, Papers, and Reports

8. Allen, J. L., "Array Antennas: New Applications for an Old Technique," IEEE Spectrum, Vol , November 1964, pp. 115-129.

9. Dolph, C. L., "A Current Distribution for Broadside Arrays Which Optimizes the Relation Between Beam Width and Side Lobe Level," Proc. IRE, Vol. 32, 1946, pp. 335-348.

10. Draus, S. M., "The Design of Acoustic Transducer Arrays Using Goal Programming," M. S. Thesis at The Pennsylvania State University, August 1977.

11. Fiacco, A. V. and McCormick, G. P.,"The sequential Unconstrained Minimization Technique for Non-linear Programming, a Primal-Dual Method," Management Science, Vol. 10, no. 2, January 1964

12. Fiacco, A. V. and McCormick, G. P., "Computational Algorithm for the Sequential Unconstrained Minimization Technique for Non-linear Programming," Management Science, Vol. 10, no. 4, July 1964

BIBLIOGRAPHY (CONTINUED)

13. Hooke, R. and Jeeves, T.A., "Direct Search Solution of Numerical and Statistical Problems," J. Assoc. Computer Machines, Vol. 8, 1961, pp. 212-229.

14. Hsiao, J. K. and Rao, J.B. L., "Computer Analysis of Conformal Phased Arrays," NRL Report 7826

15. Ignizio, J. P., "The Application of Goal Programming to Acoustic Array Design (A Methodology for Multicriteria Systems Design)" Applied Research Laboratory, Internal Memorandum, May 1977.

16. Ignizio, J. P., "An Approach to Multicriteria Design," Final Report, U. S. Army Contract; DASG6077-C-0078, April 1978.

17. Kirtland, D., Perlis, J. and Rue B., "SLGP: A Sequential Linear Goal Programming Code, Built Around MPSX," Proc. SHARE 51,(in press)

18. McMahon, G. W., Hubley, Barbara and Mohammed, A., "Design of Optimum Directional Arrays Using Linear Programming Techniques," J. Acoust. Soc. Am., Vol. 51, No. 1, 1972, pp. 304-309.

19. Wang, H. S. C., "Amplitude Shading of Sonar Transducer Arrays," J. Acoust. Soc. Am., Vol. 57, No. 5, May, 1975, pp. 1076-1084.

20. Wilson, G. L., "Computer Optimization of Transducer Array Patterns," J. Acoust. Soc. Am., Vol. 59, No. 1, January, 1976, pp. 195-203.

DISTRIBUTION

Commander (NSEA 09G32)
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362 Copies 1 and 2

Commander (NSEA 0342)
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362 Copies 3 and 4

Defense Documentation Center
5010 Duke Street
Cameron Station
Alexandria, VA 22314 Copies 5 through 16